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(12) United States Patent
Suzuki

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(45) Date of Patent: Apr. 26, 2016

(54) **PRESSURE SENSOR, SENSOR ARRAY, METHOD FOR MANUFACTURING SENSOR ARRAY, AND GRASPING APPARATUS**

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(72) Inventor: **Hironori Suzuki**, Chino (JP)

(73) Assignee: **Seiko Epson Corporation** (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 317 days.

(21) Appl. No.: **13/967,867**

(22) Filed: **Aug. 15, 2013**

(65) **Prior Publication Data**

US 2013/0331978 A1 Dec. 12, 2013

Related U.S. Application Data

(62) Division of application No. 13/105,247, filed on May 11, 2011, now Pat. No. 8,539,839.

(30) **Foreign Application Priority Data**

Mar. 28, 2011 (JP) 2011-069518
May 9, 2011 (JP) 2011-104095

(51) **Int. Cl.**

G01L 9/00	(2006.01)
G01L 5/22	(2006.01)
G01L 9/08	(2006.01)
G01L 11/06	(2006.01)
B25J 13/08	(2006.01)
H01L 27/20	(2006.01)
H01L 41/113	(2006.01)
H01L 41/332	(2013.01)
H01L 41/22	(2013.01)
G01L 1/02	(2006.01)

(52) **U.S. Cl.**

CPC ***G01L 5/226*** (2013.01); ***B25J 13/082*** (2013.01); ***G01L 1/02*** (2013.01); ***G01L 9/0022*** (2013.01); ***G01L 9/08*** (2013.01); ***G01L 11/06*** (2013.01); ***H01L 27/20*** (2013.01); ***H01L 41/1132*** (2013.01); ***H01L 41/22*** (2013.01); ***H01L 41/332*** (2013.01); *Y10T 29/42* (2015.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,142,912 A * 9/1992 Frische G01L 9/0016 338/4
6,004,644 A * 12/1999 Takeuchi C04B 35/486 264/603

(Continued)

FOREIGN PATENT DOCUMENTS

JP 2006-319945 A 11/2006

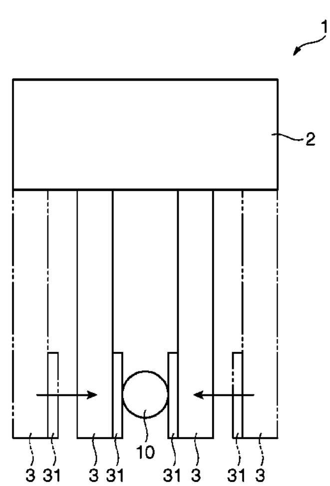
Primary Examiner — Andre Allen

(74) *Attorney, Agent, or Firm* — Harness, Dickey & Pierce, P.L.C.

(57) **ABSTRACT**

A pressure sensor includes: a supporting body which has an opening; a pressure detecting portion which includes a supporting film provided on the supporting body and having a diaphragm portion closing the opening, and a piezoelectric body provided on the diaphragm portion and deflecting to output an electric signal; a frame body which has, on the pressure detecting portion, a cylindrical cavity along a film thickness direction of the supporting film, and is formed, in plan view when viewed from the film thickness direction of the supporting film, at a position where a cylindrical inner peripheral wall of the cavity overlaps with the opening, or outside of the opening; a sealing film which closes the frame body; and a silicone oil which is filled in an inner space formed of the cylindrical inner peripheral wall of the cavity, the sealing film, and the pressure detecting portion.

6 Claims, 27 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,271,621	B1 *	8/2001	Ito	G01L 1/16 310/358
7,259,032	B2	8/2007	Murata et al.	
2004/0100164	A1	5/2004	Murata et al.	
2006/0144154	A1 *	7/2006	Ueno	G01L 1/16 73/723
2008/0030205	A1 *	2/2008	Fujii	B81B 7/02 324/661
2009/0085441	A1 *	4/2009	Morris	G01L 9/0022 310/338
2011/0273519	A1	11/2011	Miyazawa	
2013/0112910	A1	5/2013	Noguchi et al.	
2015/0075289	A1 *	3/2015	Cogliati	G01L 9/0044 73/721

* cited by examiner

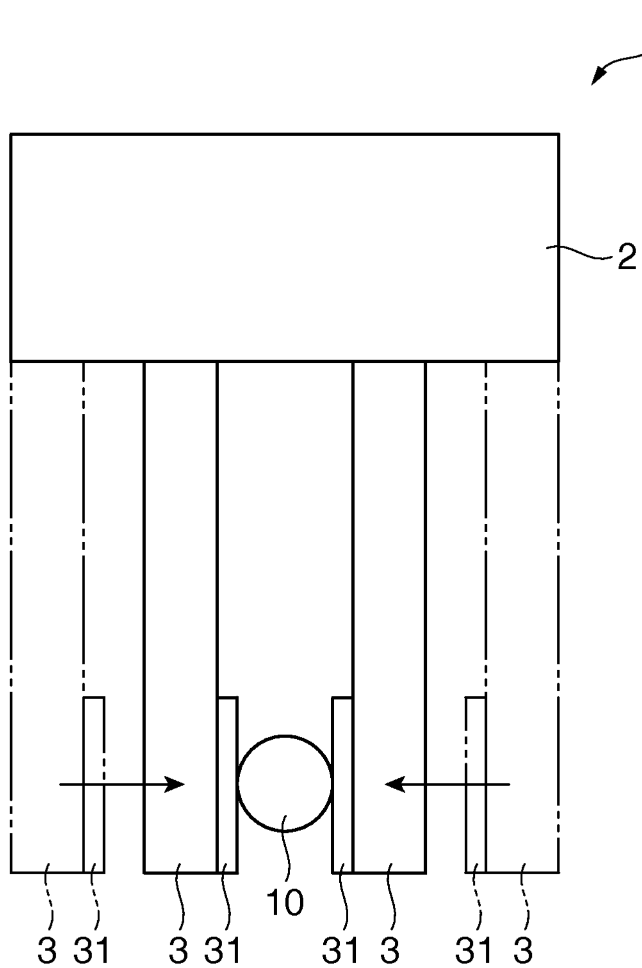


FIG. 1

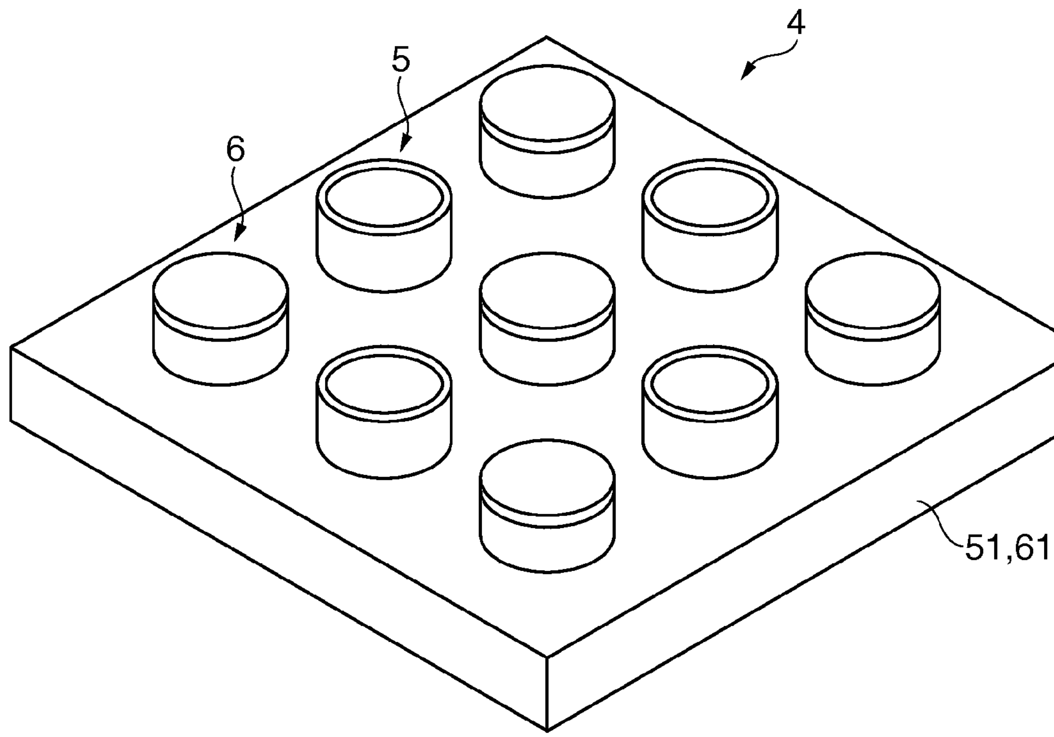


FIG. 2

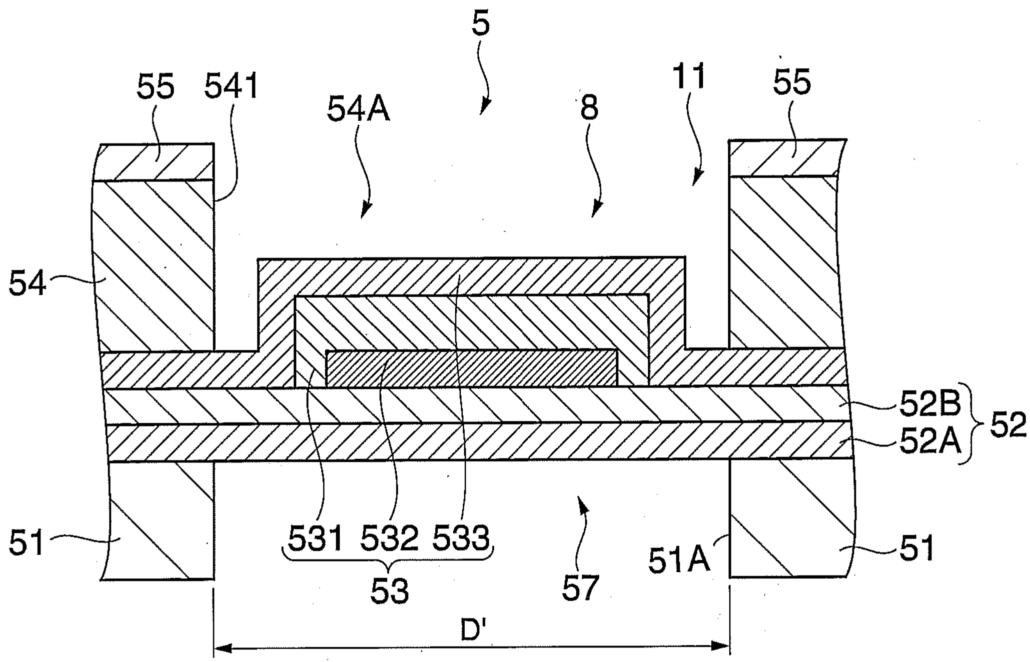

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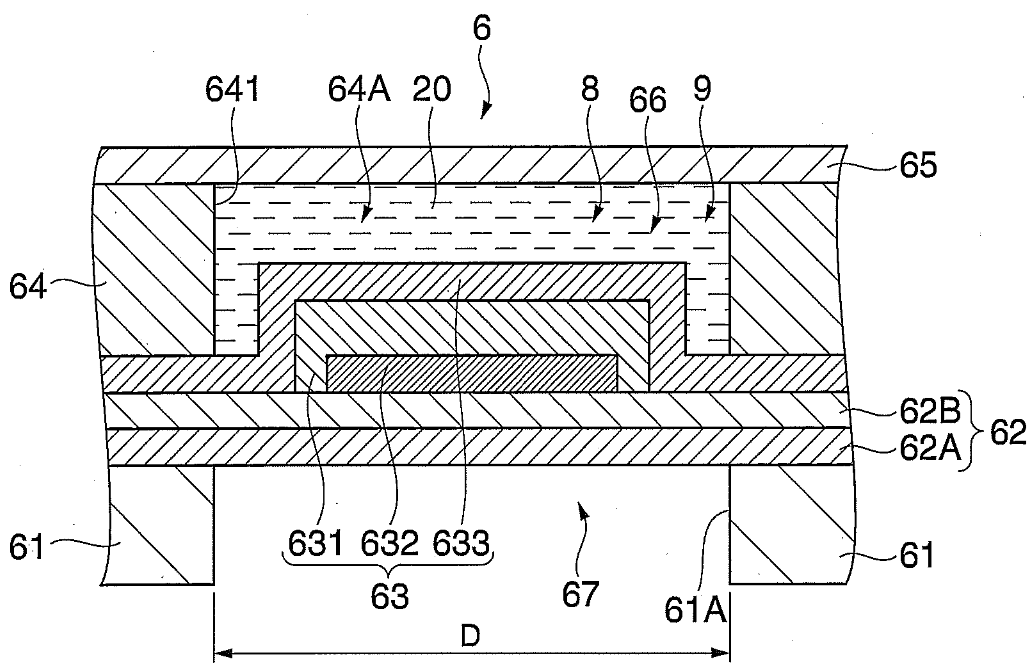
FIG. 3A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631 632 633
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61A
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D

FIG. 3B

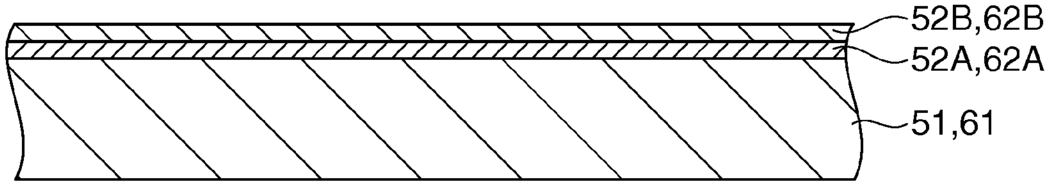


FIG. 4A

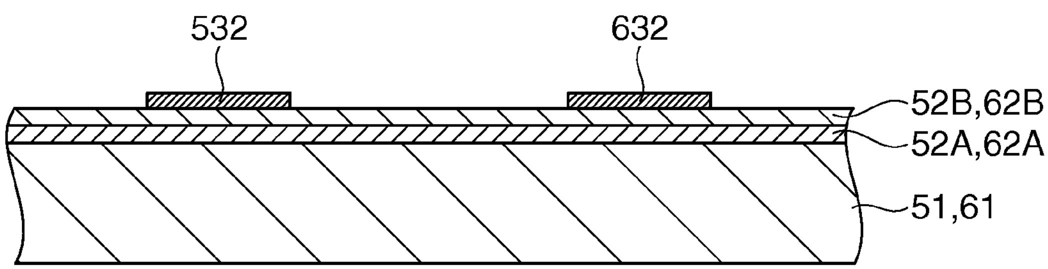


FIG. 4B

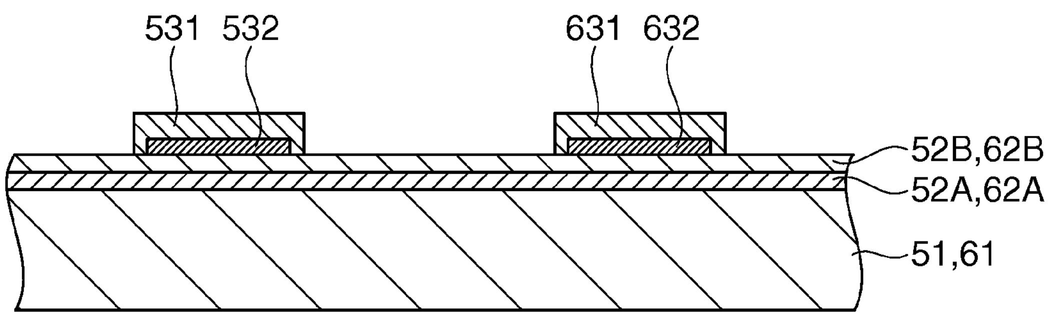


FIG. 4C

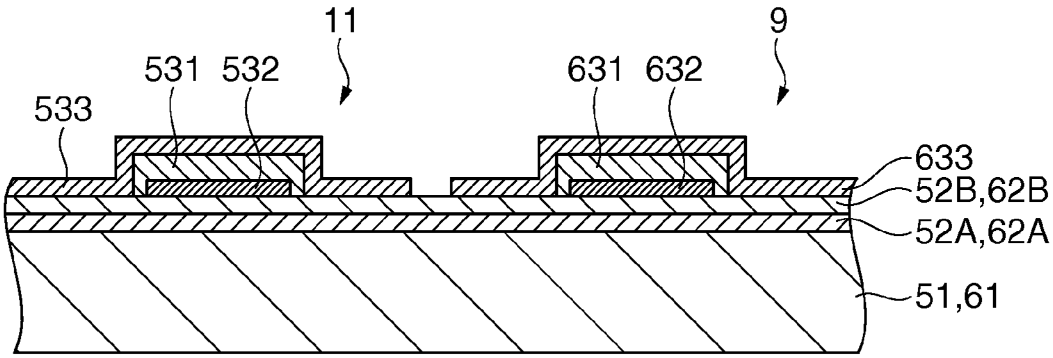


FIG. 5A

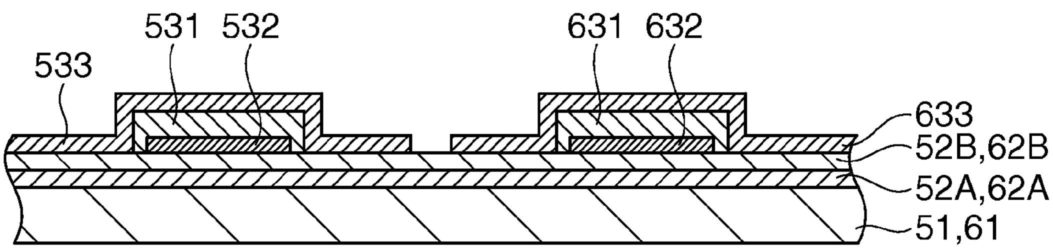


FIG. 5B

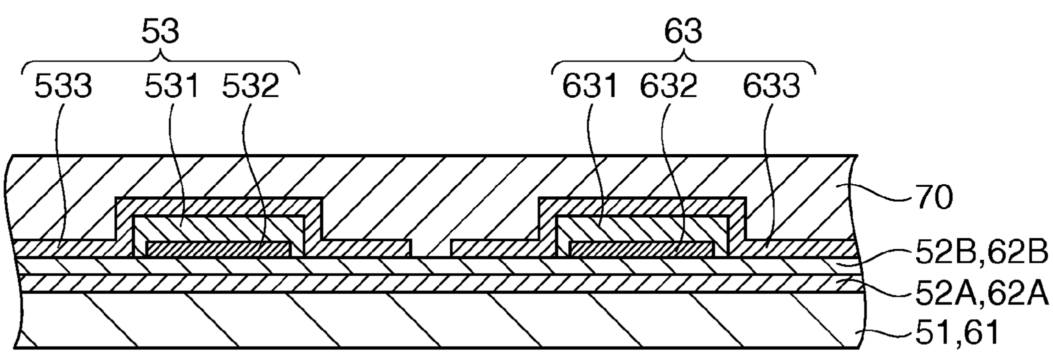


FIG. 5C

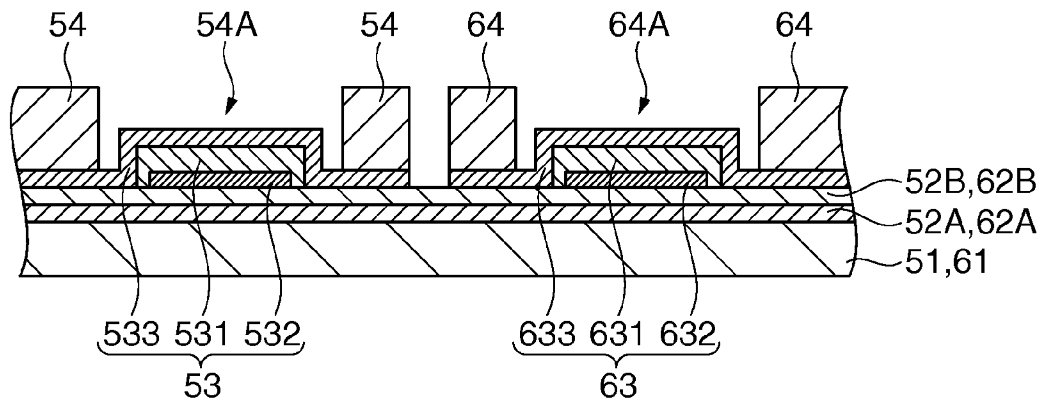


FIG. 6A

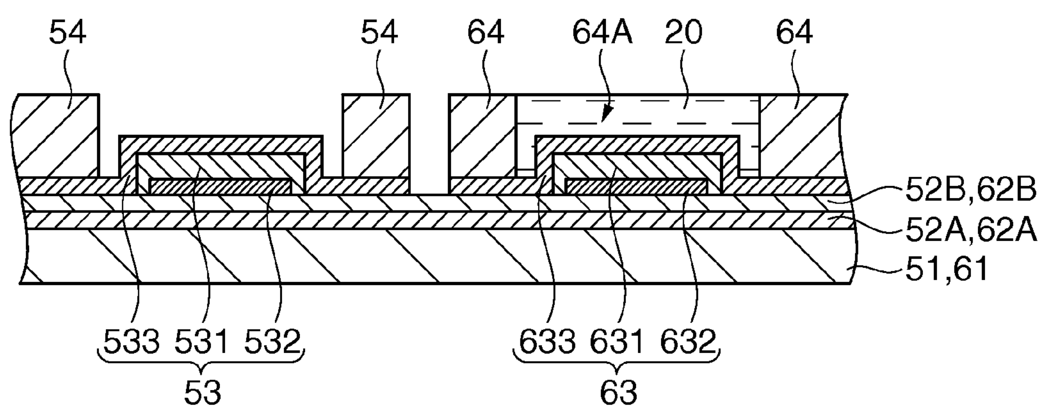


FIG. 6B

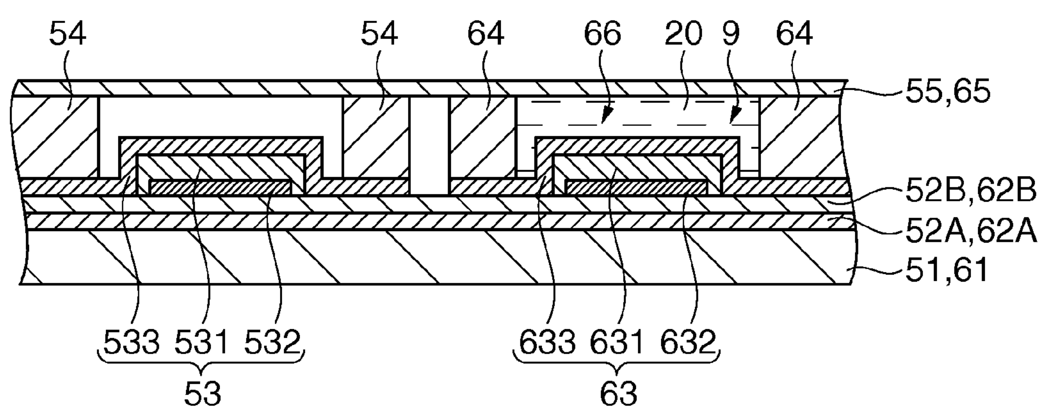
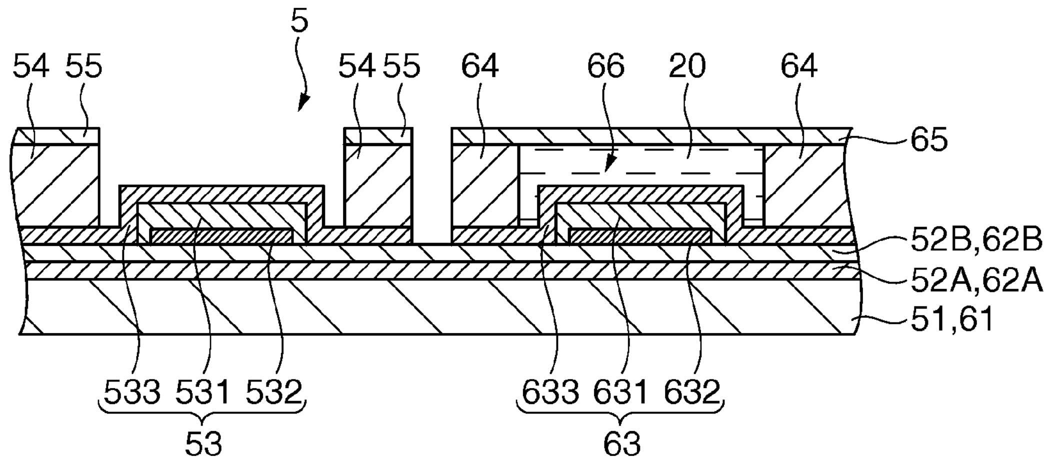


FIG. 6C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633 631 632
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FIG. 7A

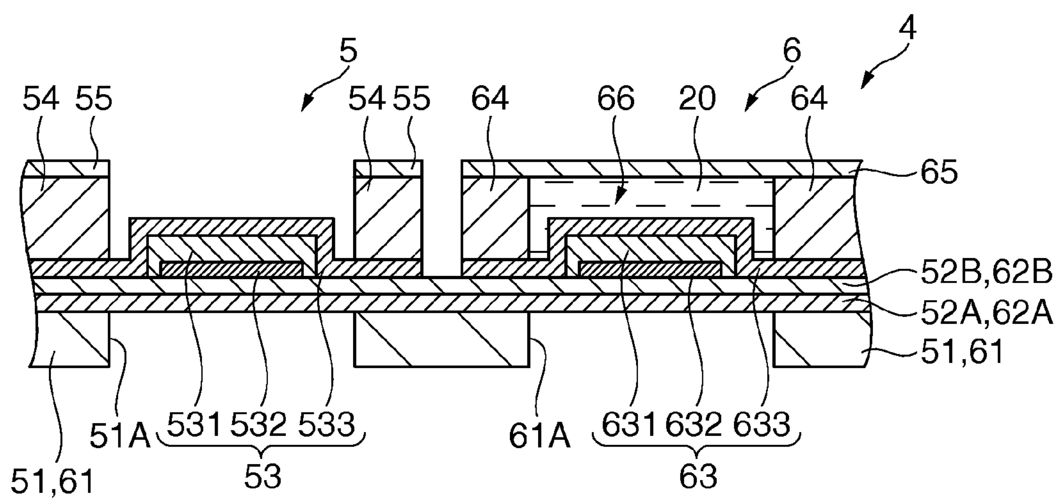
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FIG. 7B

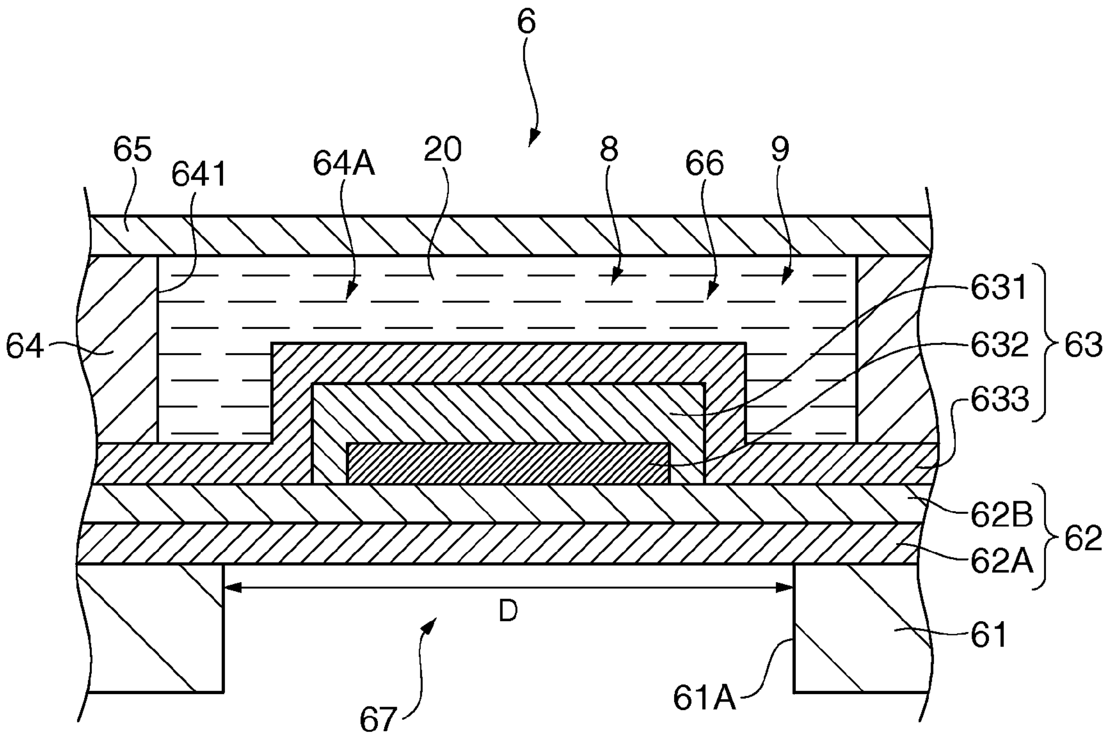


FIG. 8

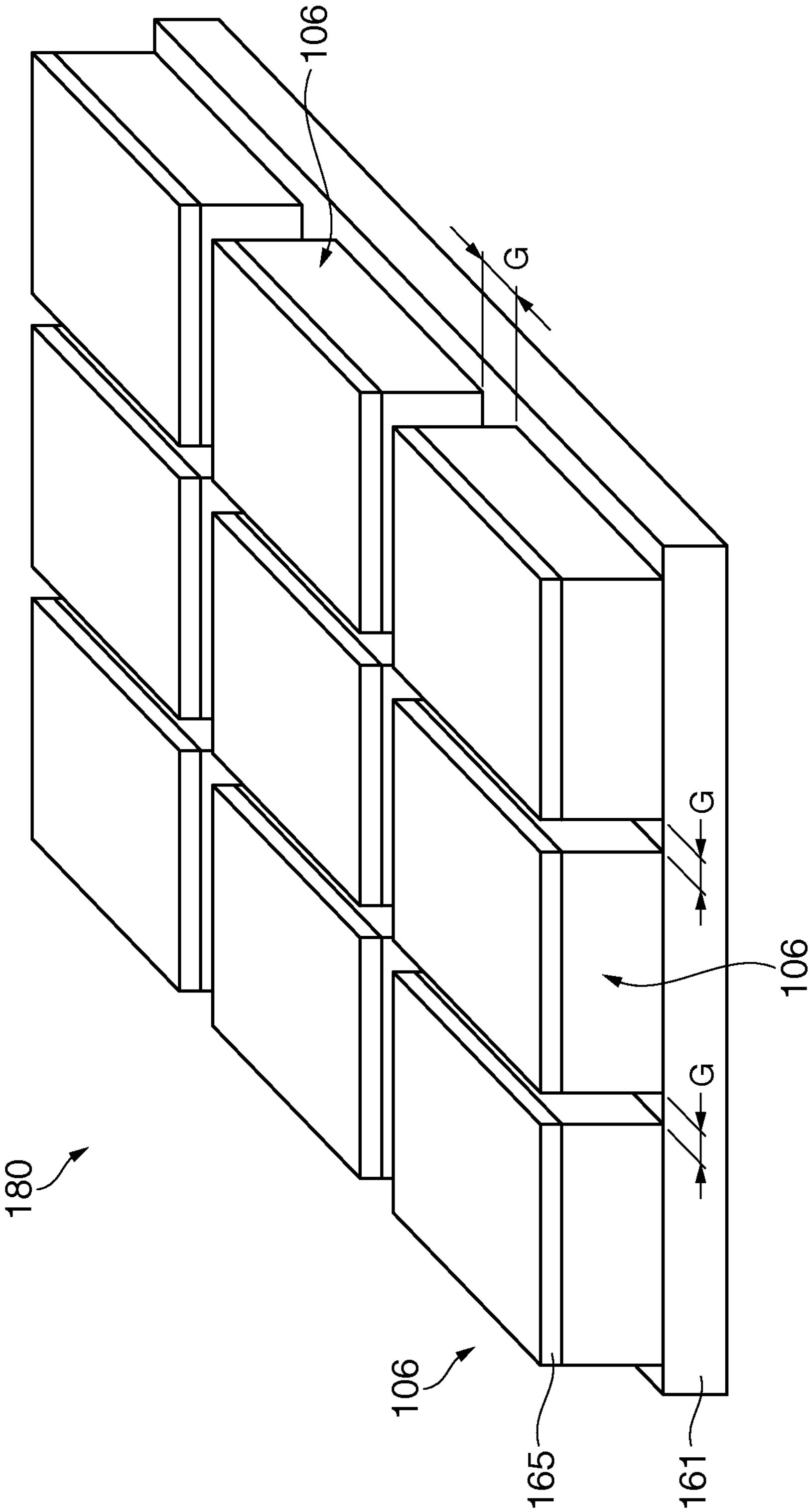


FIG. 9

FIG. 10A

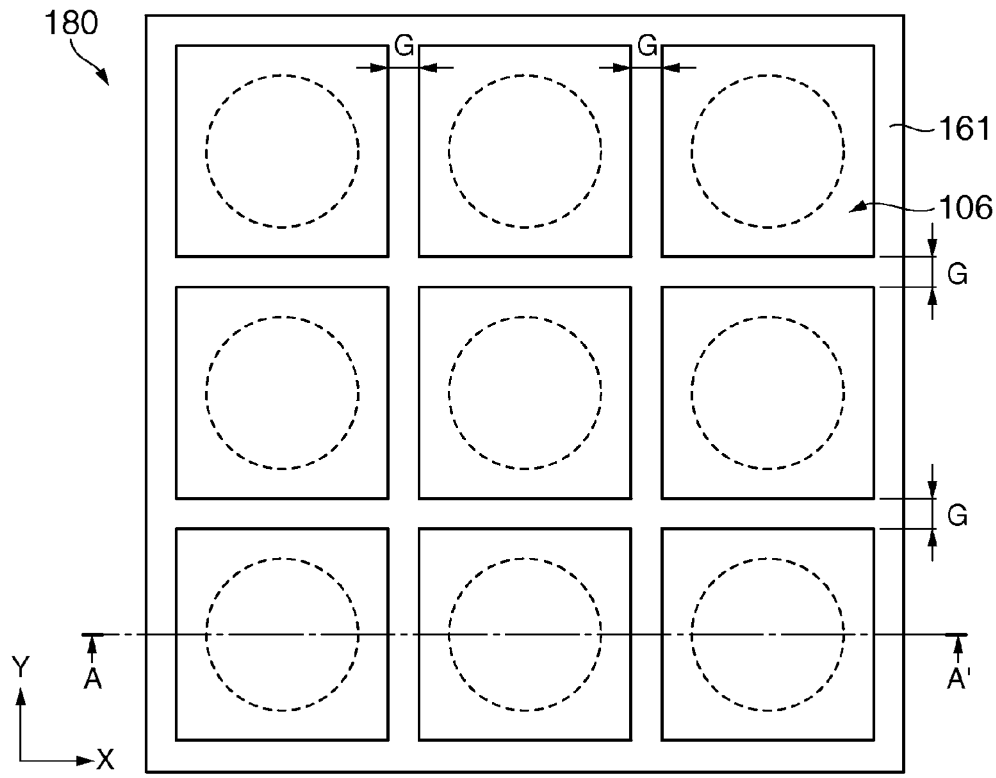


FIG. 10B

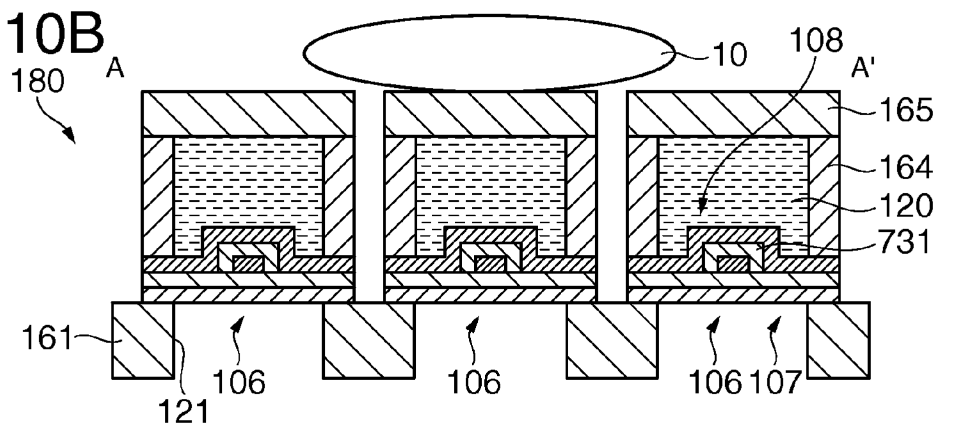
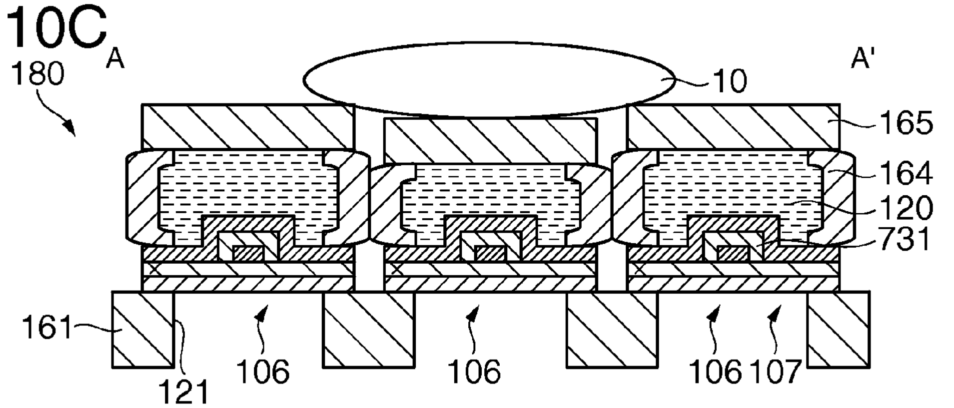


FIG. 10C



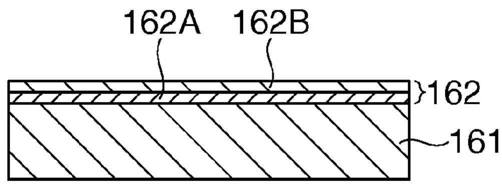


FIG. 11A

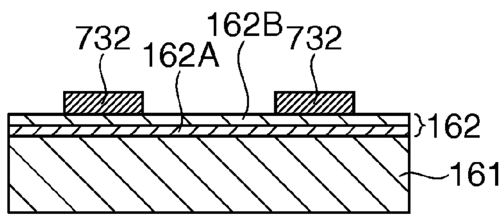
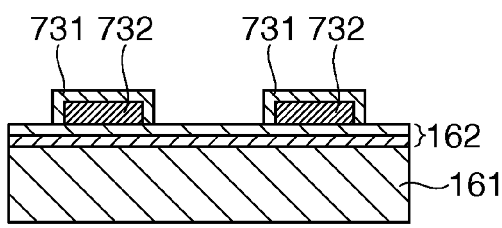


FIG. 11B



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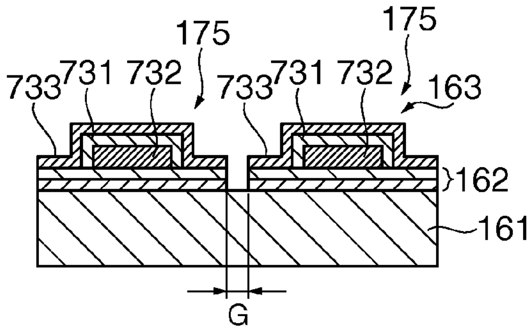


FIG. 11D

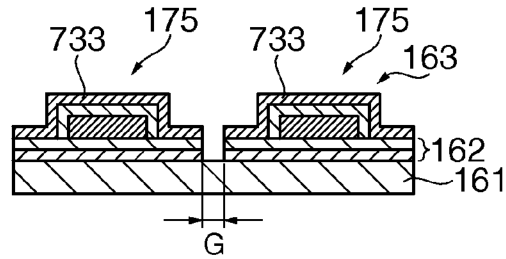


FIG. 11E

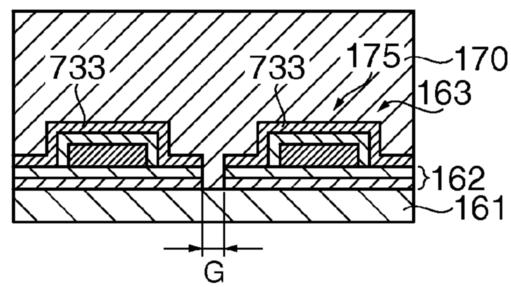


FIG. 11F

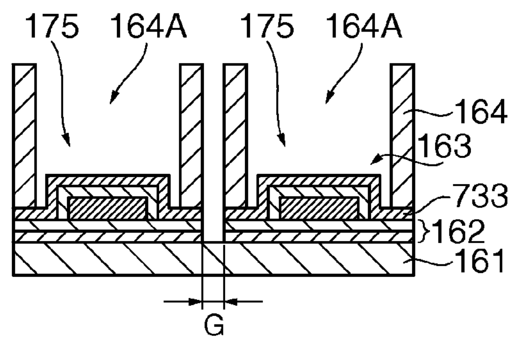


FIG. 11G

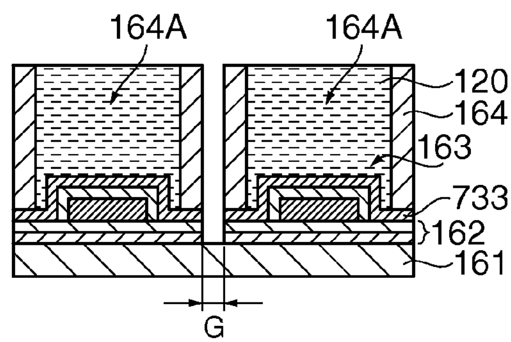


FIG. 11H

FIG. 12A

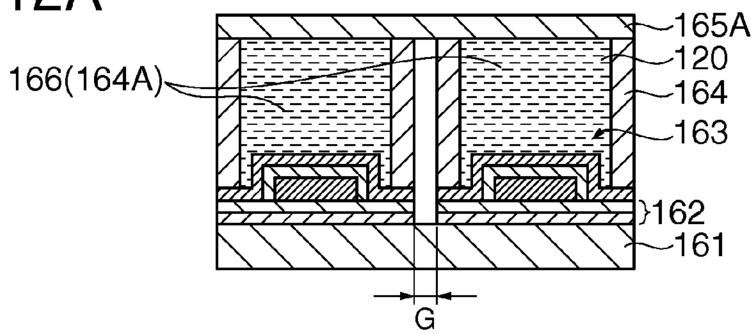


FIG. 12B

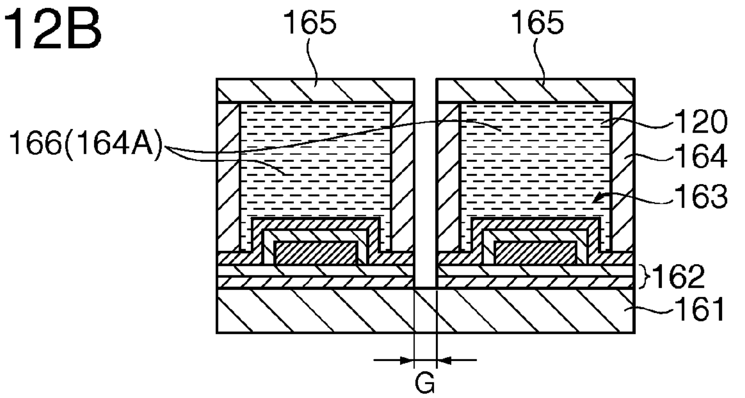


FIG. 12C

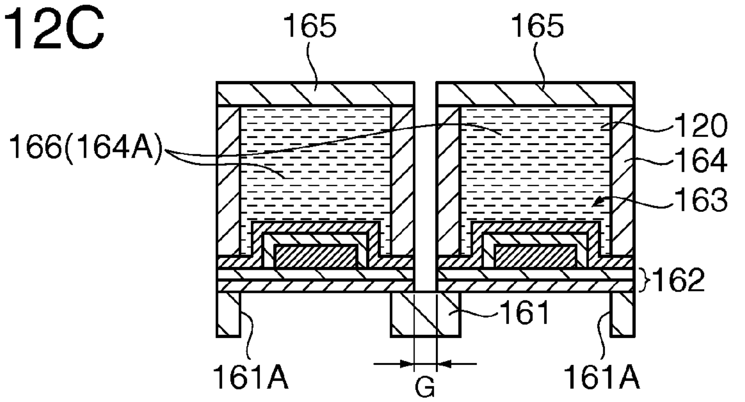
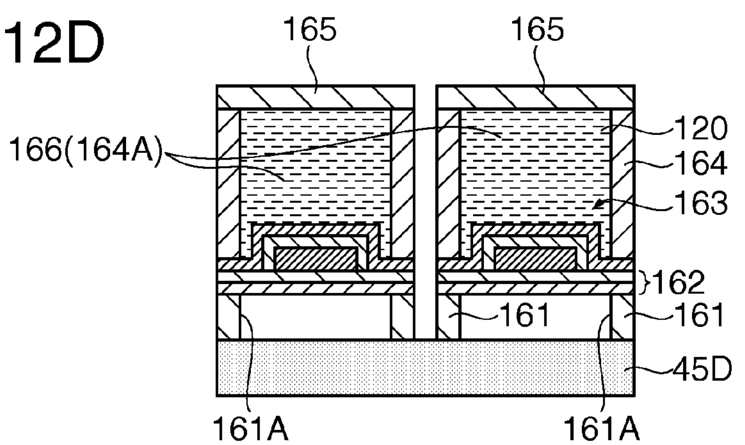


FIG. 12D



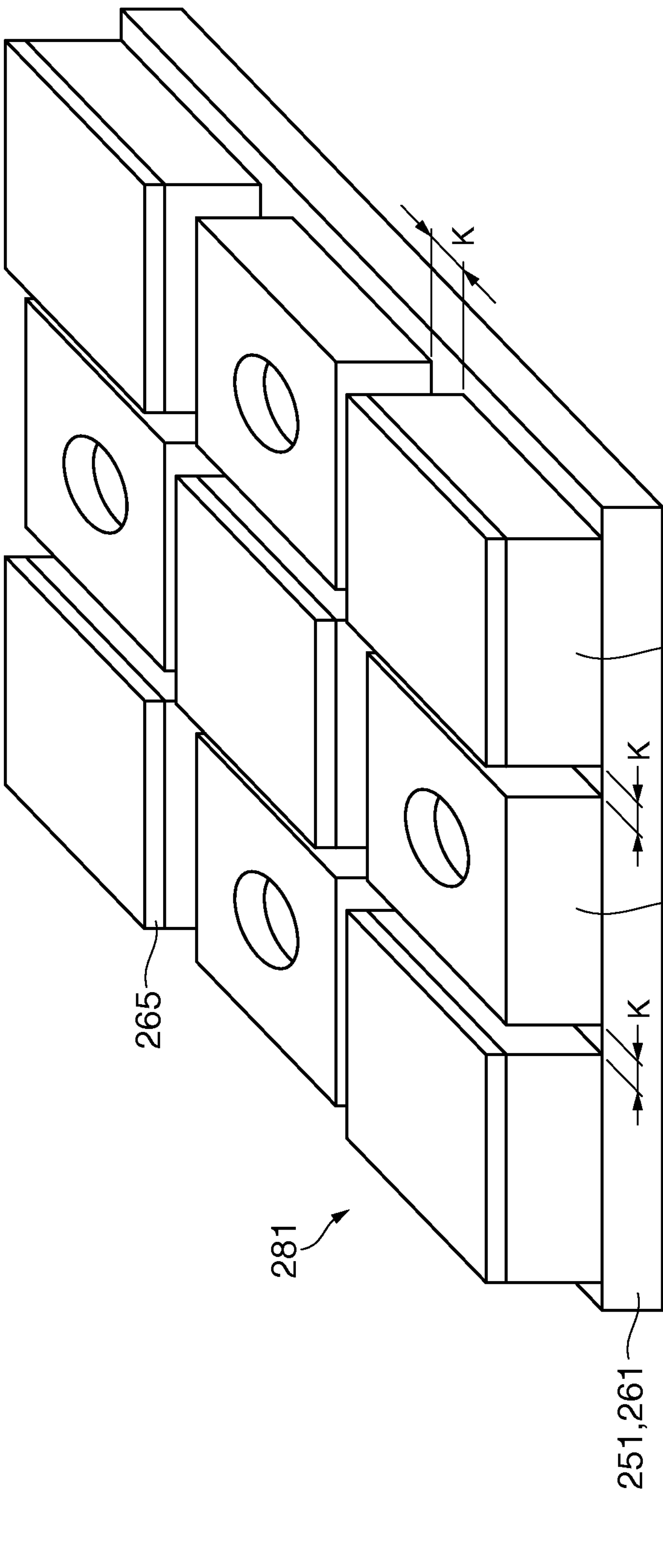


FIG. 13

FIG. 14A

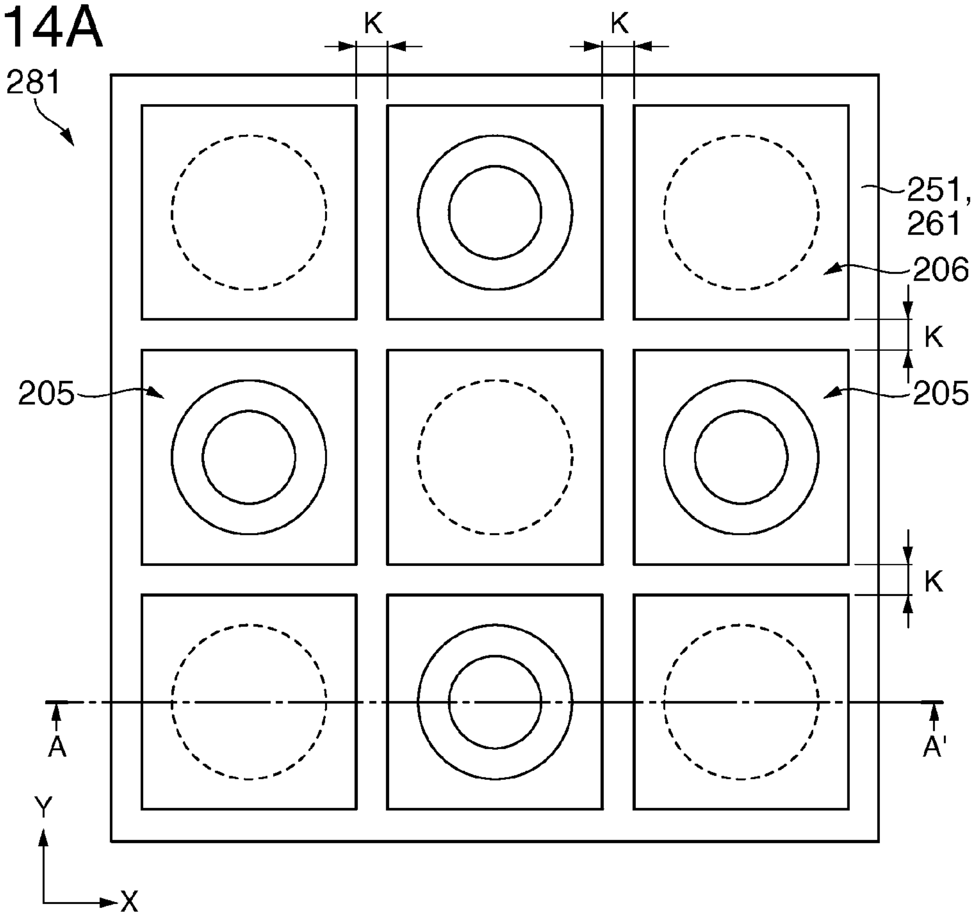
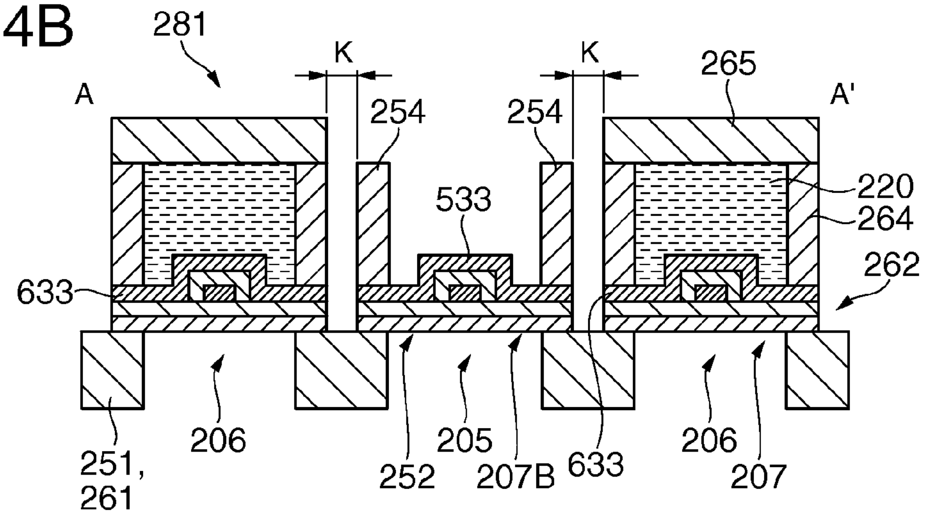


FIG. 14B



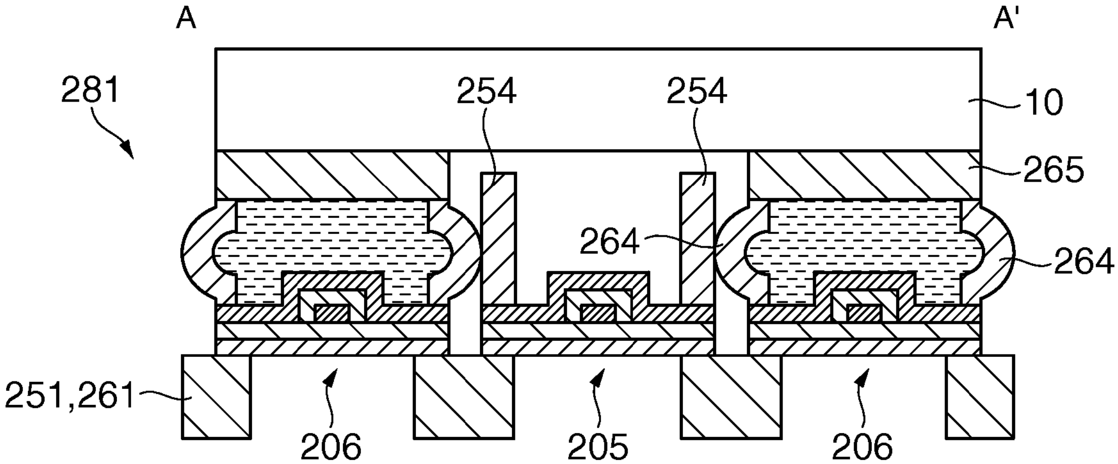


FIG. 15A

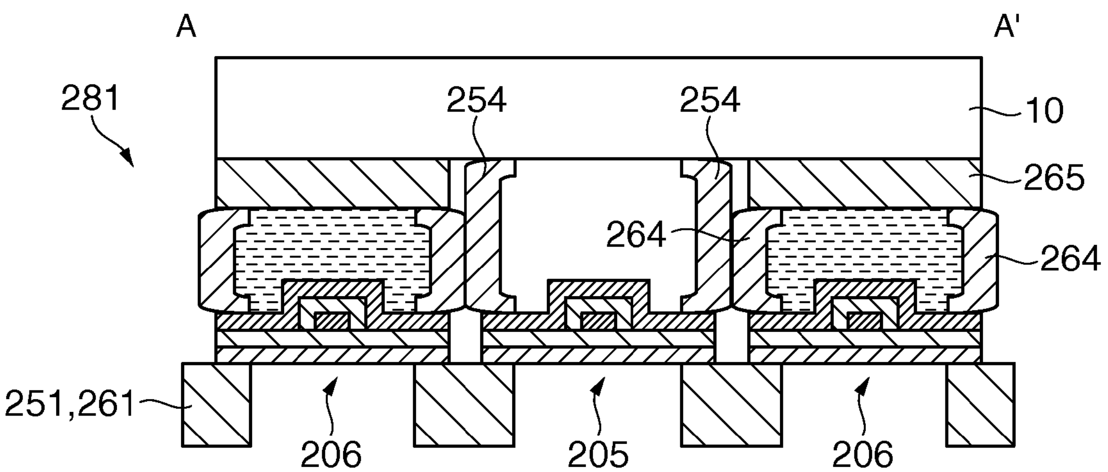


FIG. 15B

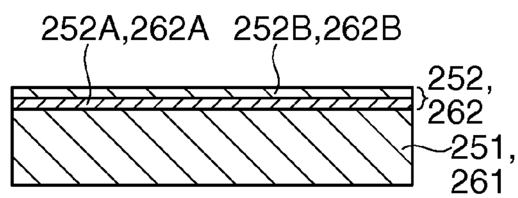


FIG. 16A

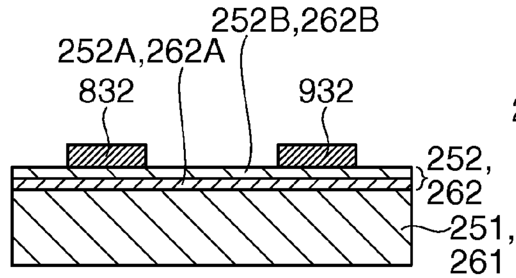


FIG. 16B

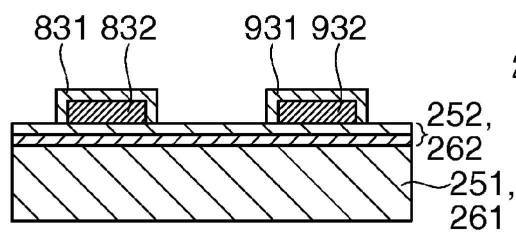


FIG. 16C

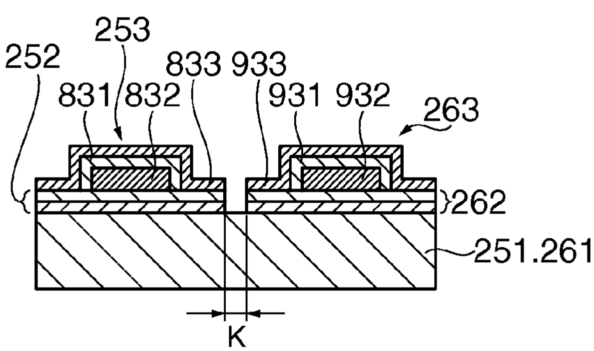


FIG. 16D

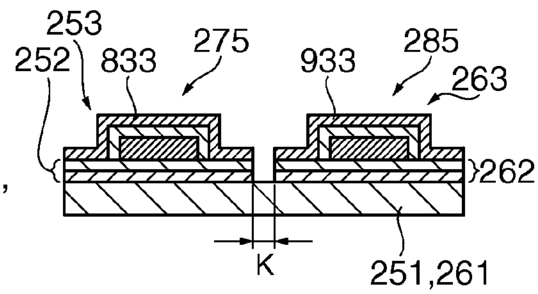


FIG. 16E

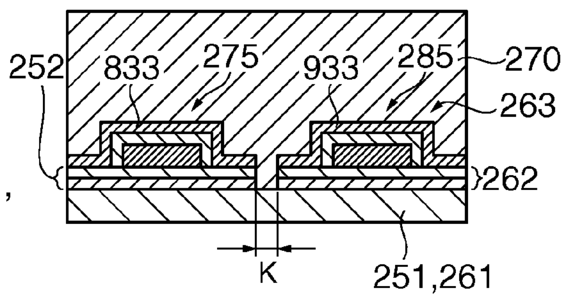


FIG. 16F

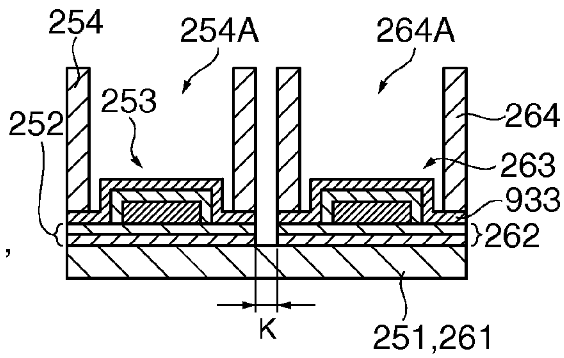


FIG. 16G

FIG. 17A

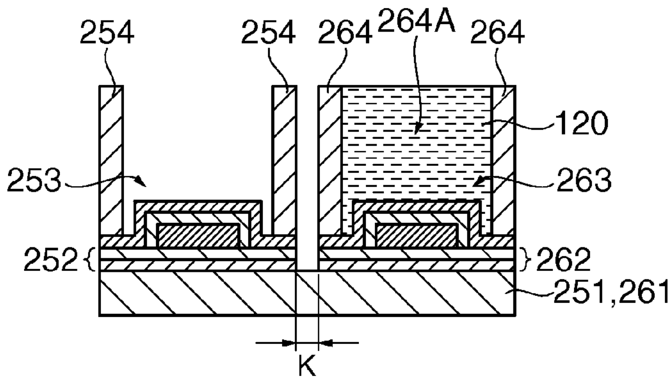


FIG. 17B

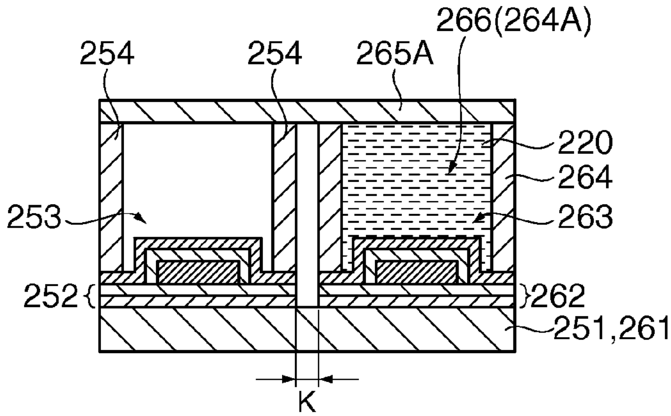


FIG. 17C

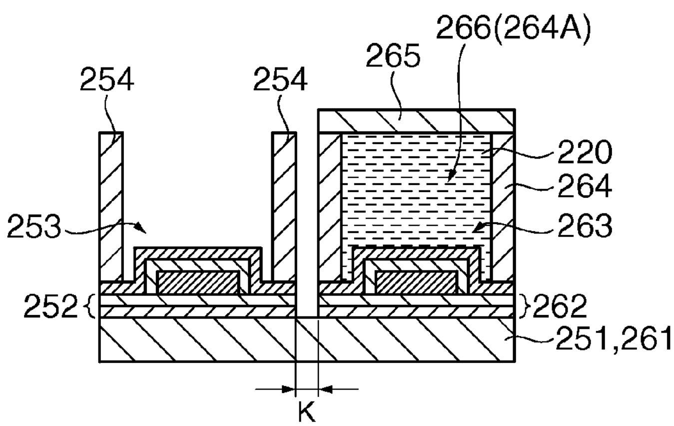
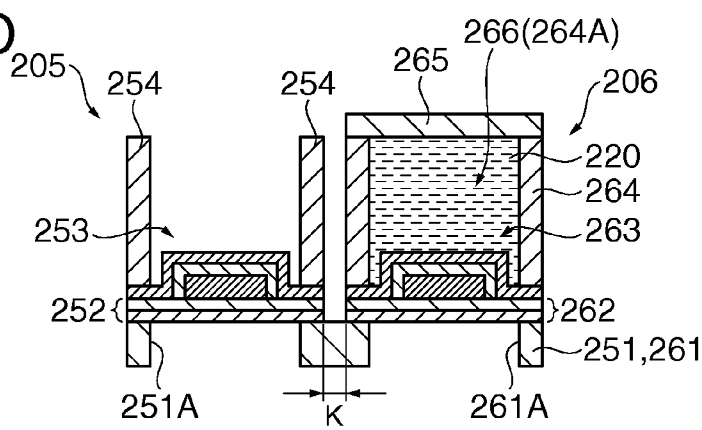


FIG. 17D



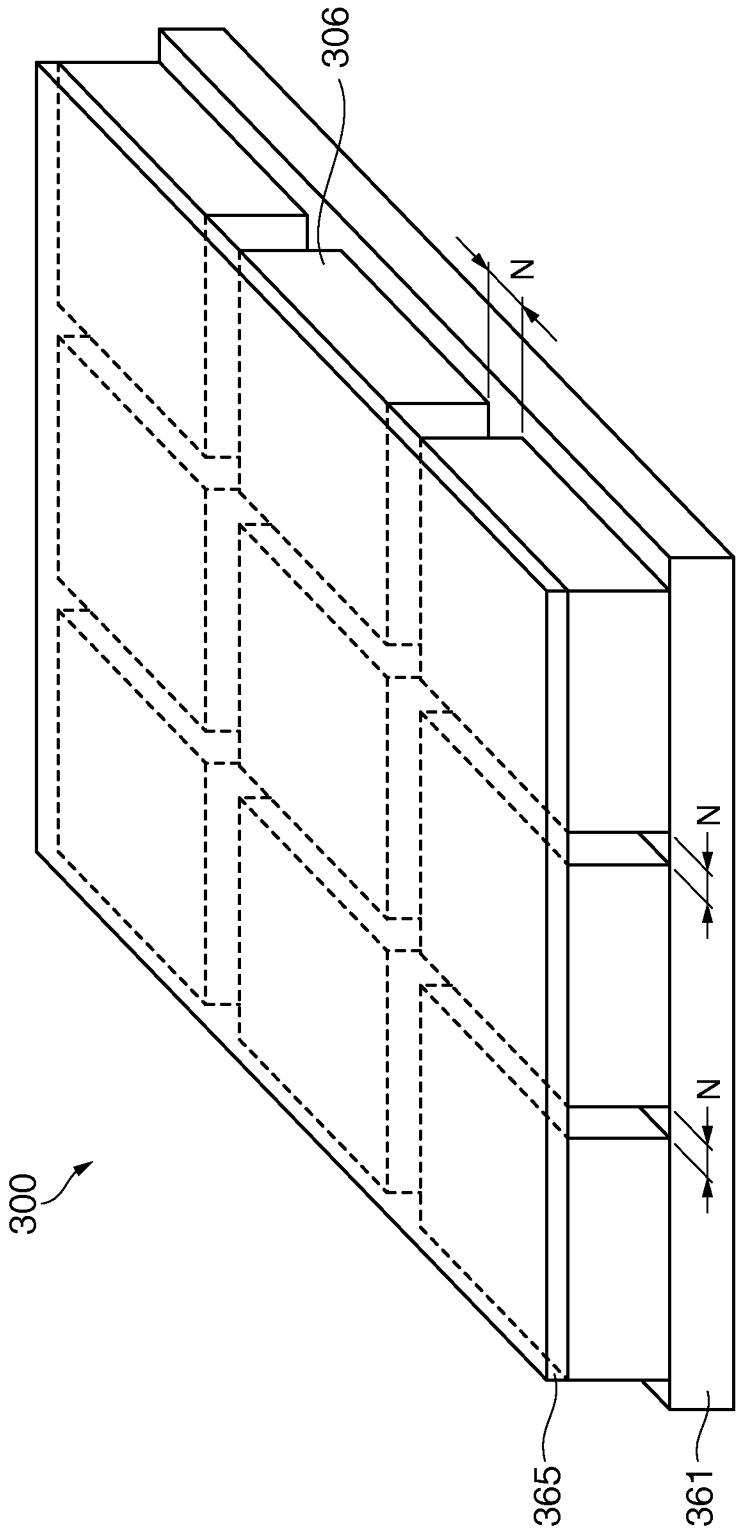


FIG. 18

FIG. 19A

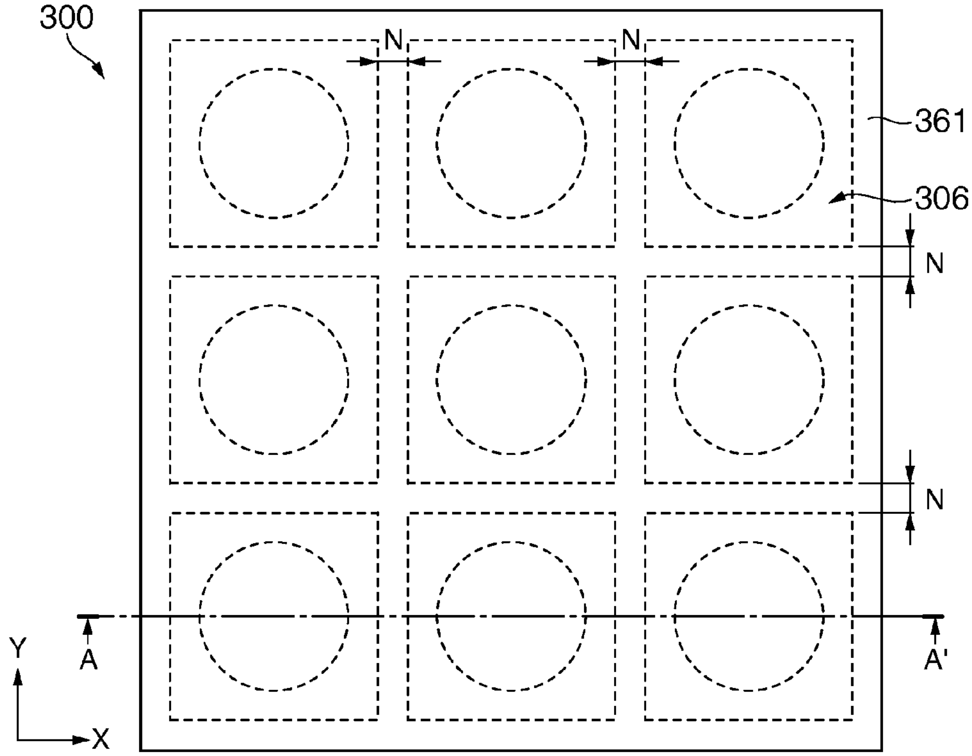


FIG. 19B

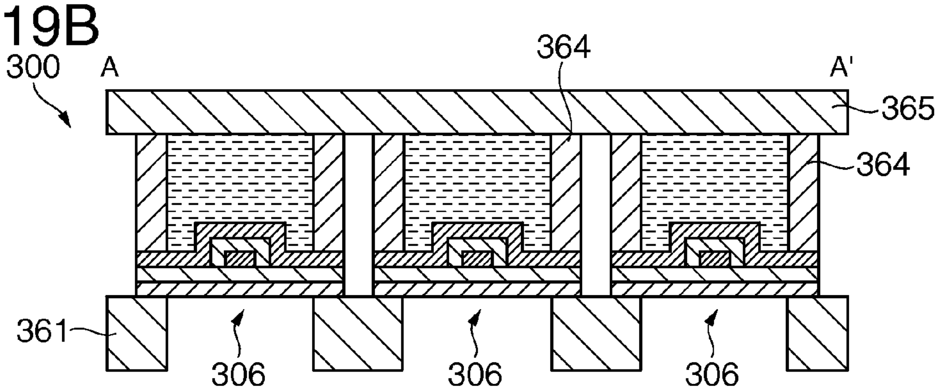
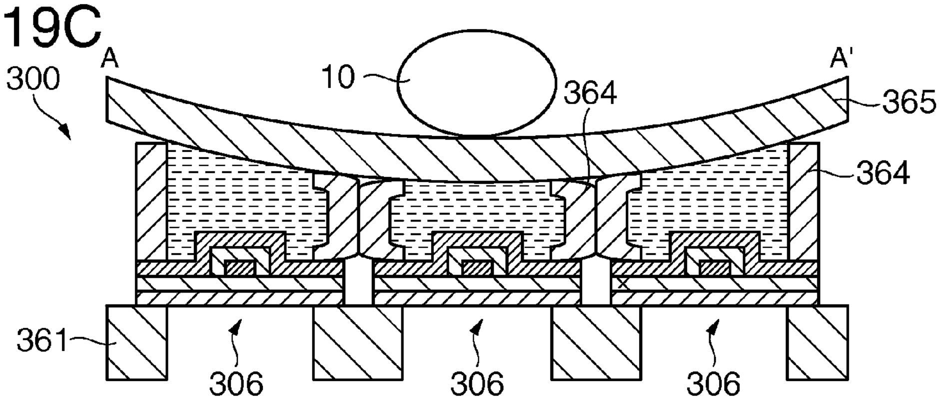


FIG. 19C



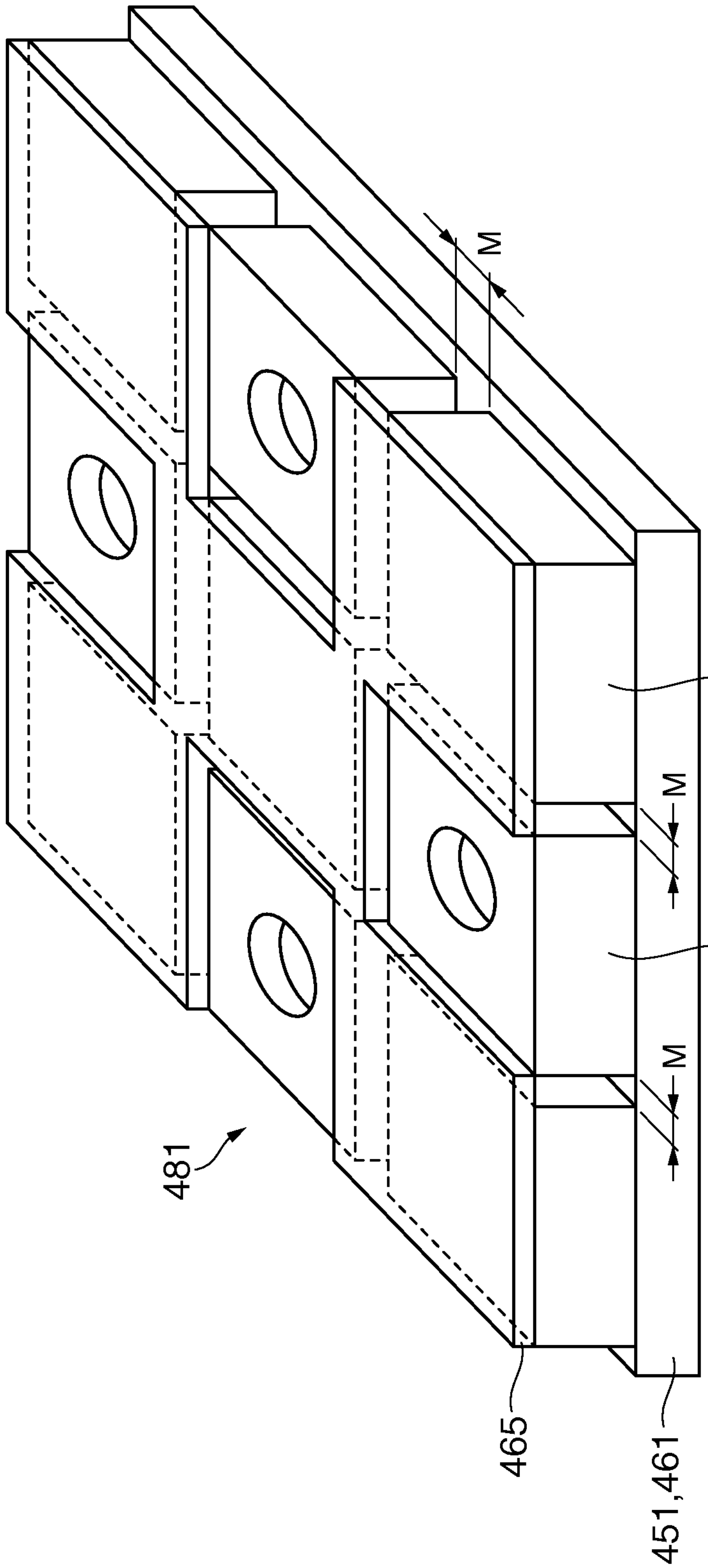


FIG. 20

FIG. 21A

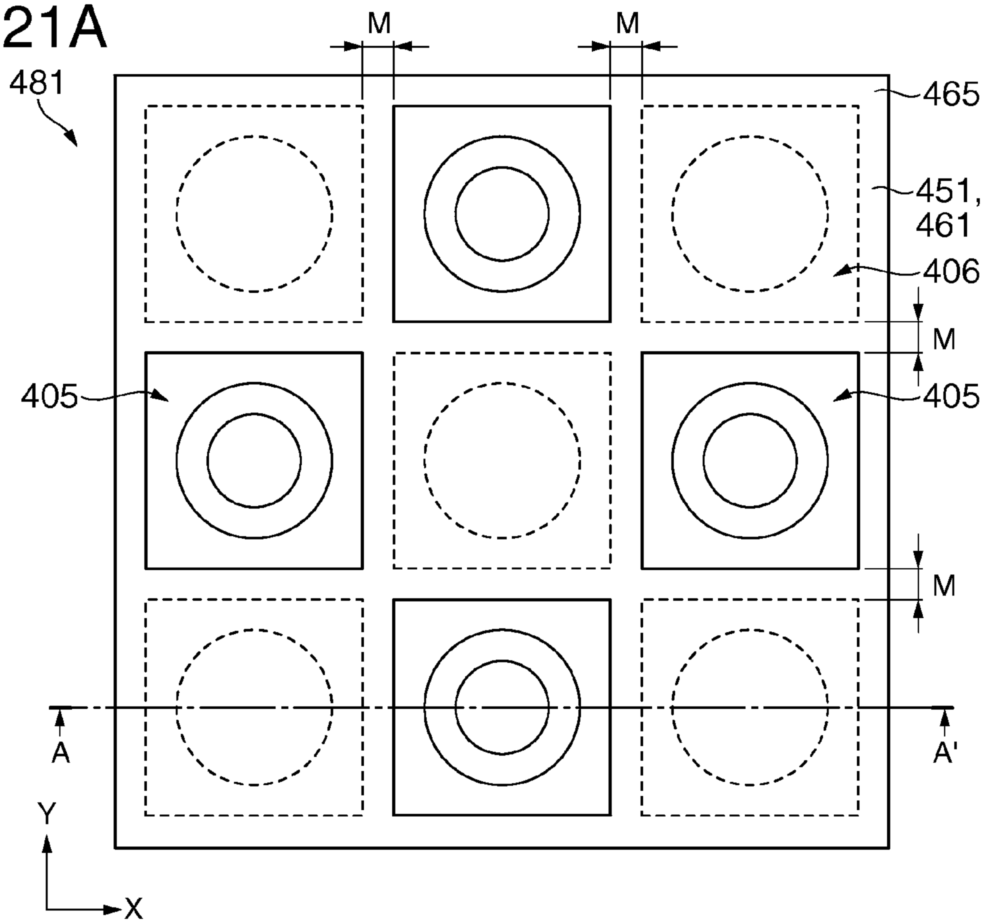
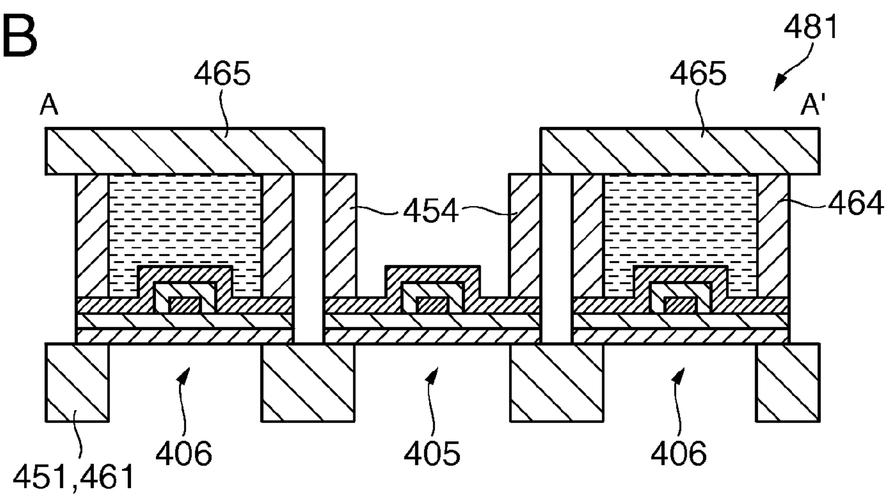
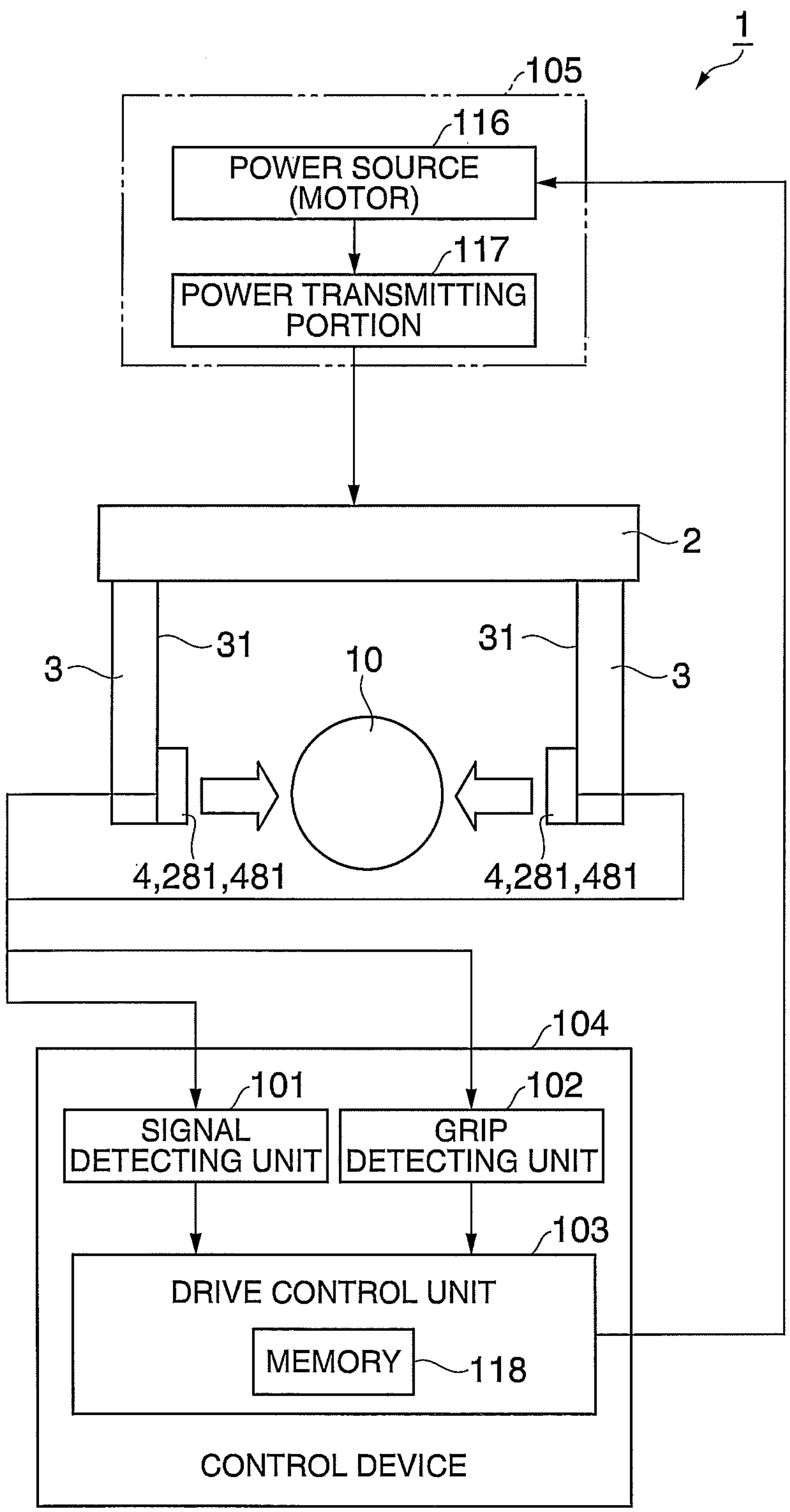


FIG. 21B

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105
116
POWER SOURCE (MOTOR)
117
POWER TRANSMITTING PORTION
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3
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10
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3
4,281,481
4,281,481
104
101
SIGNAL DETECTING UNIT
102
GRIP DETECTING UNIT
103
DRIVE CONTROL UNIT
MEMORY
118
CONTROL DEVICE

FIG. 22

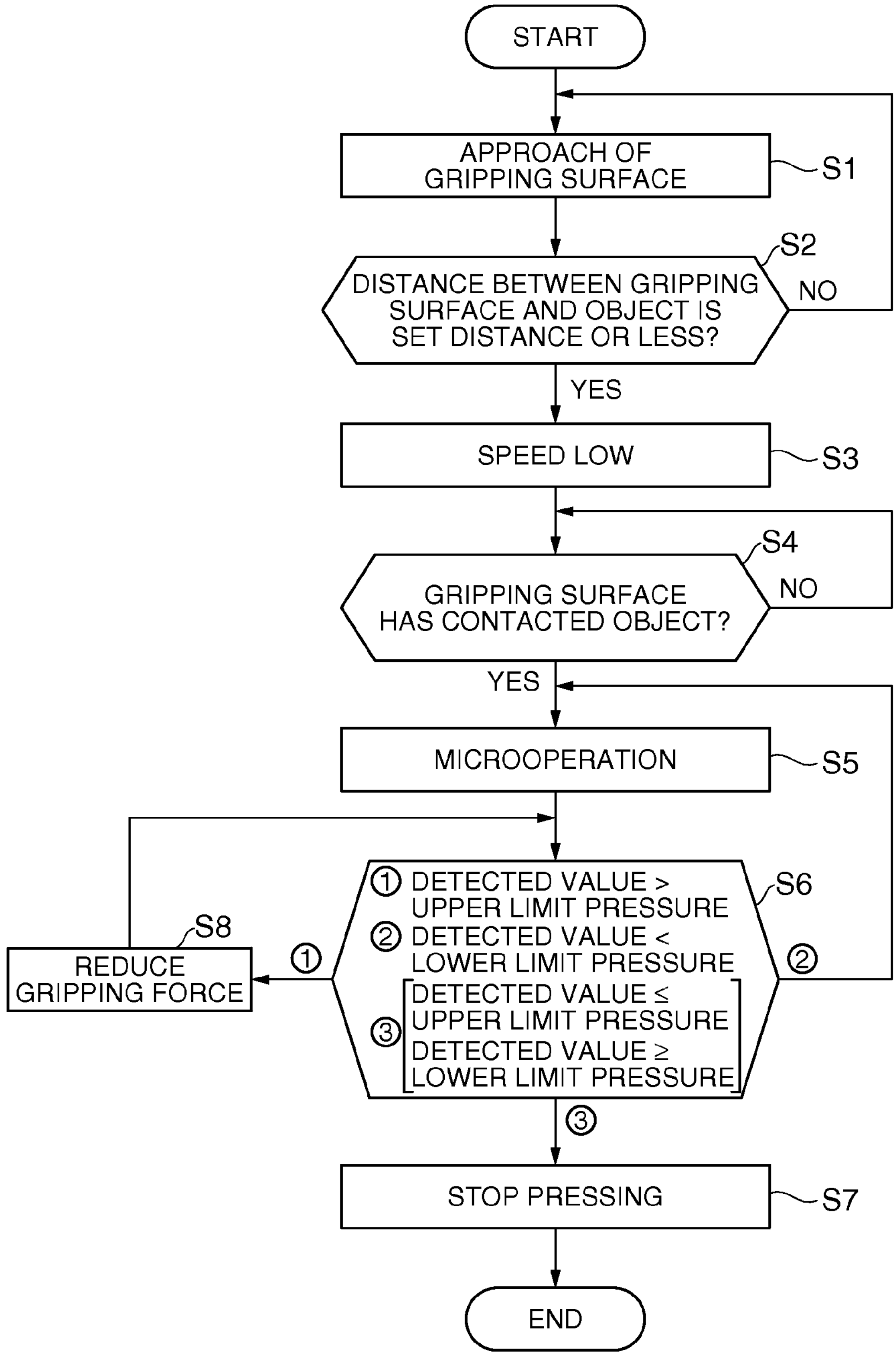

START
APPROACH OF GRIPPING SURFACE
S1
S2
DISTANCE BETWEEN GRIPPING SURFACE AND OBJECT IS SET DISTANCE OR LESS?
NO
YES
SPEED LOW
S3
S4
GRIPPING SURFACE HAS CONTACTED OBJECT?
NO
YES
MICROOPERATION
S5
S6
1 DETECTED VALUE > UPPER LIMIT PRESSURE
2 DETECTED VALUE < LOWER LIMIT PRESSURE
3 DETECTED VALUE ≤ UPPER LIMIT PRESSURE DETECTED VALUE ≥ LOWER LIMIT PRESSURE
S8
REDUCE GRIPPING FORCE
1
2
3
STOP PRESSING
S7
END

FIG. 23

FIG. 24A

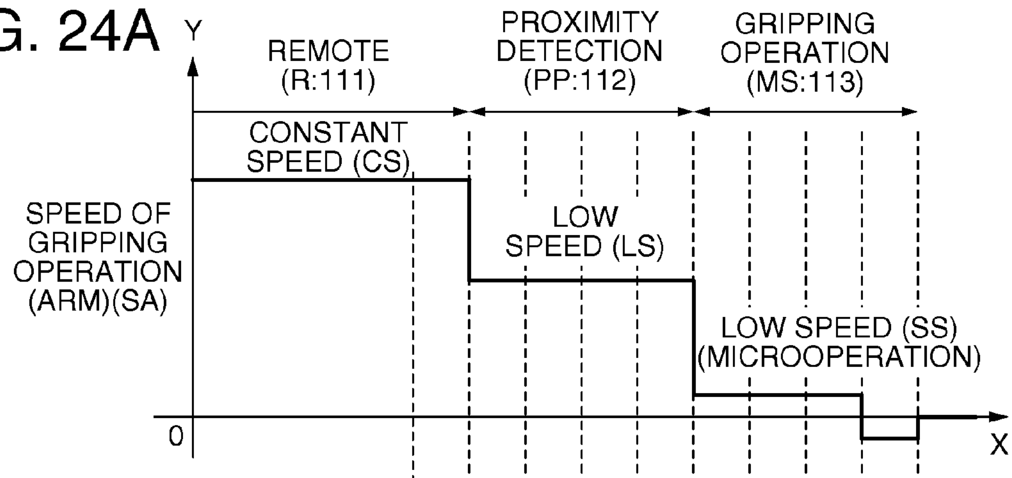


FIG. 24B

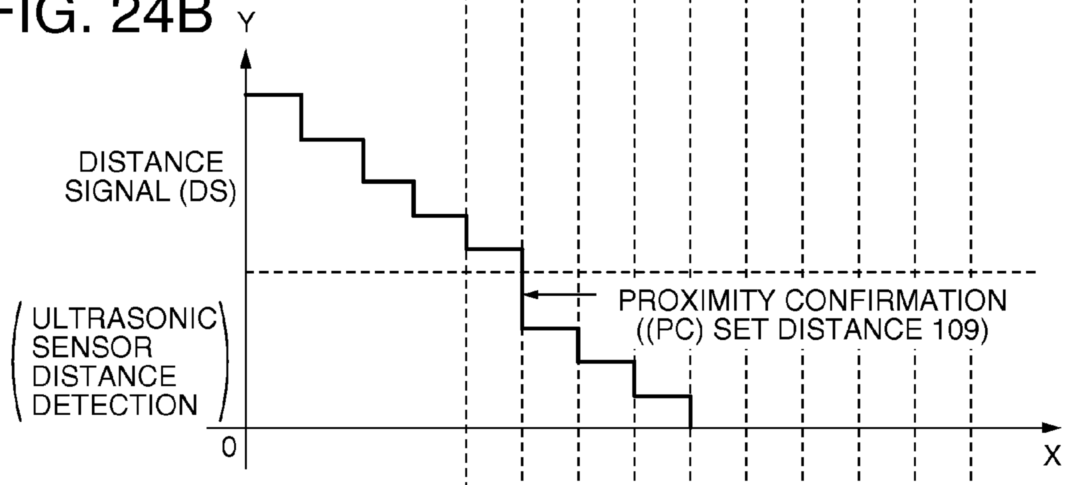
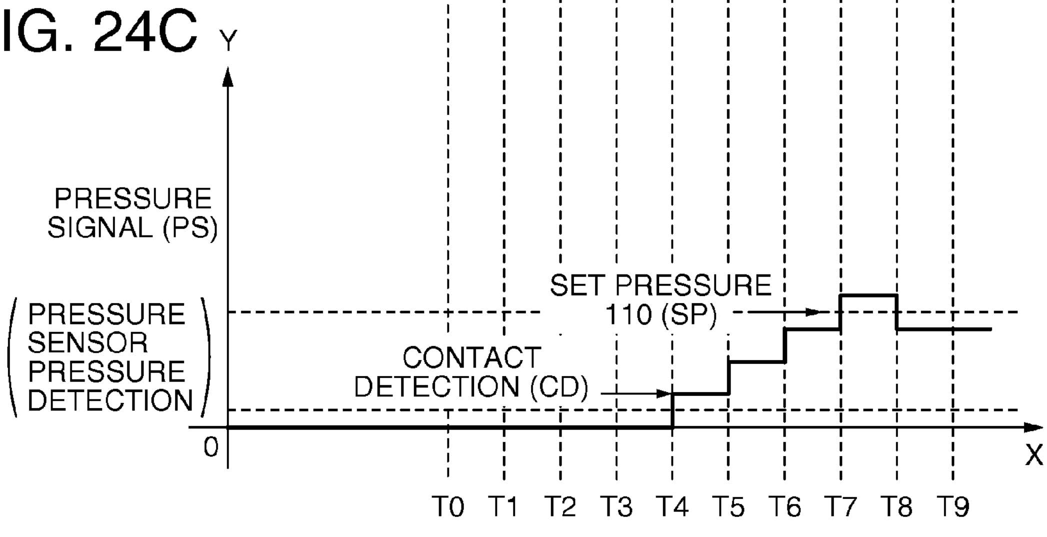


FIG. 24C



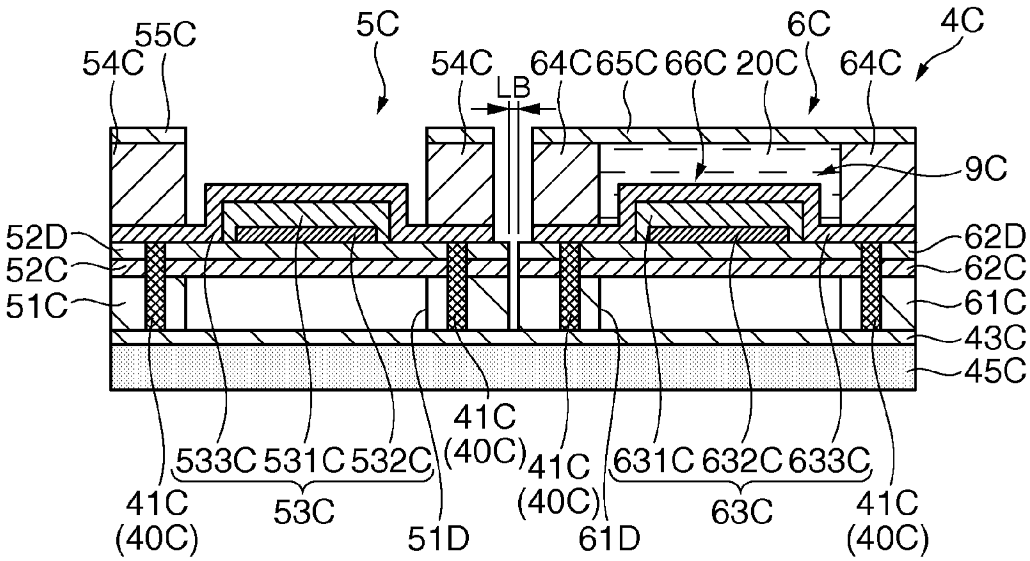

55C
54C
5C
54C
LB
64C
65C
66C
20C
6C
64C
4C
9C
52D
52C
51C
62D
62C
61C
43C
45C
533C
531C
532C
41C
(40C)
41C
(40C)
631C
632C
633C
53C
63C
41C
(40C)
51D
61D
41C
(40C)

FIG. 25

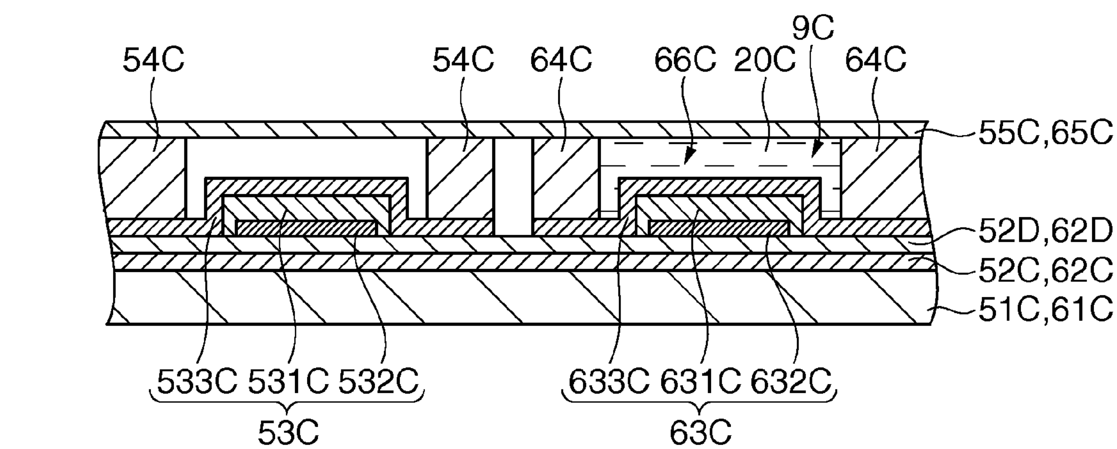

54C
54C
64C
66C
20C
9C
64C
55C,65C
52D,62D
52C,62C
51C,61C
533C
531C
532C
53C
633C
631C
632C
63C

FIG. 26

FIG. 27A

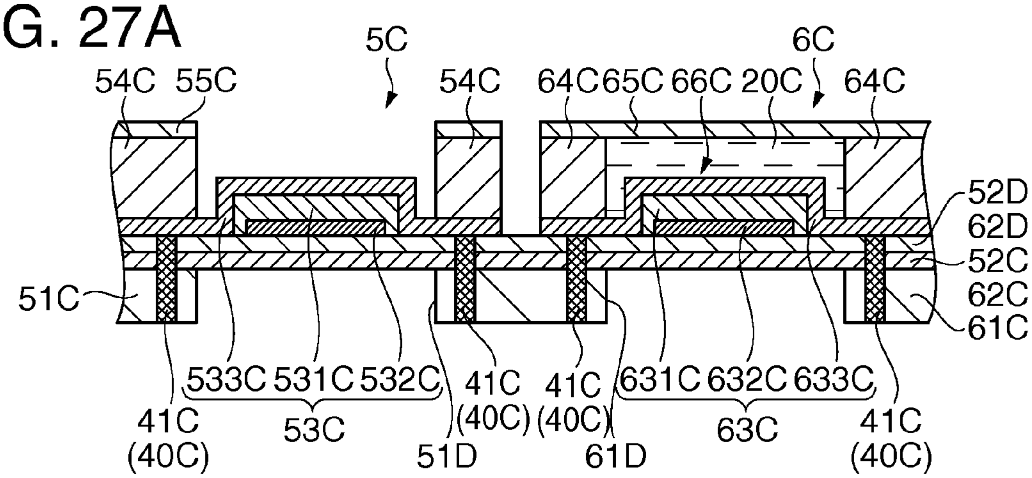


FIG. 27B

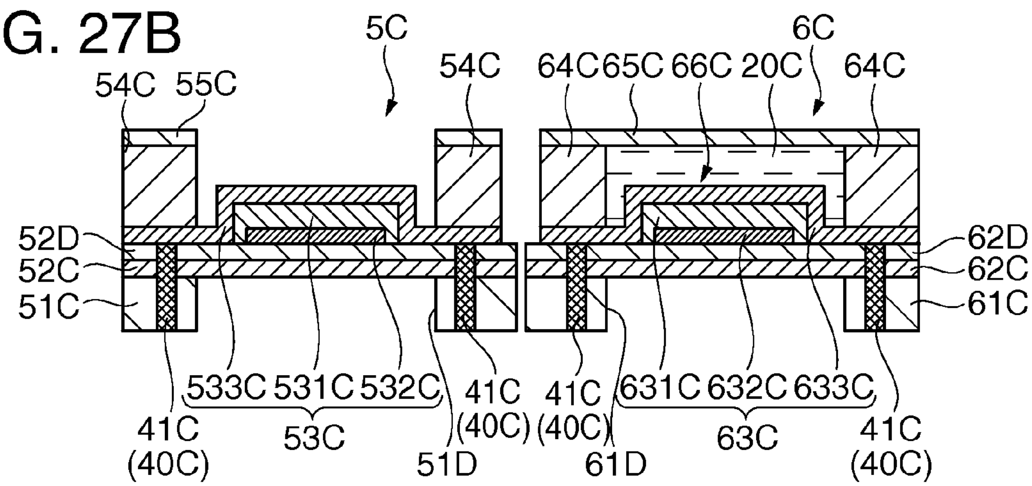
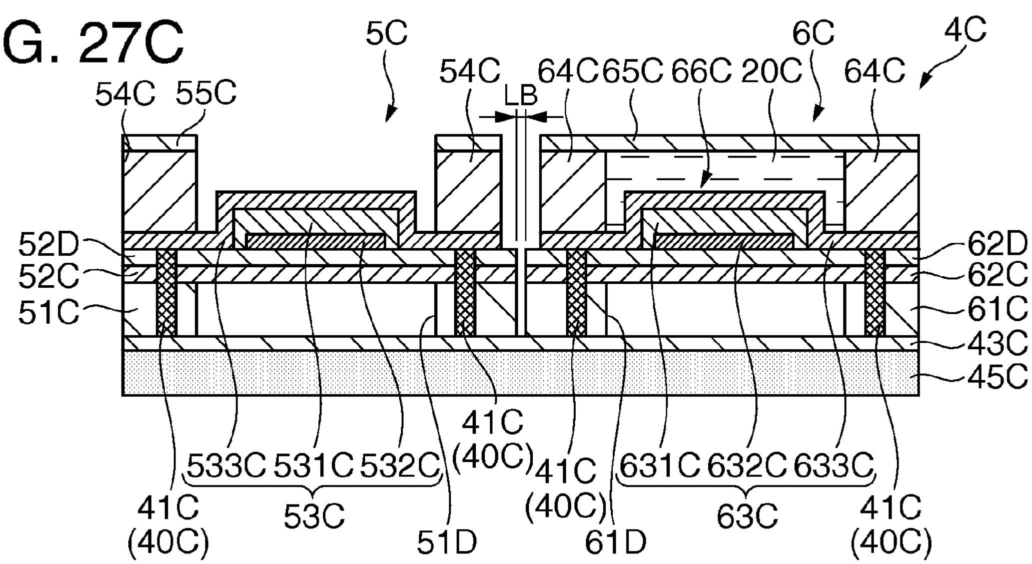


FIG. 27C



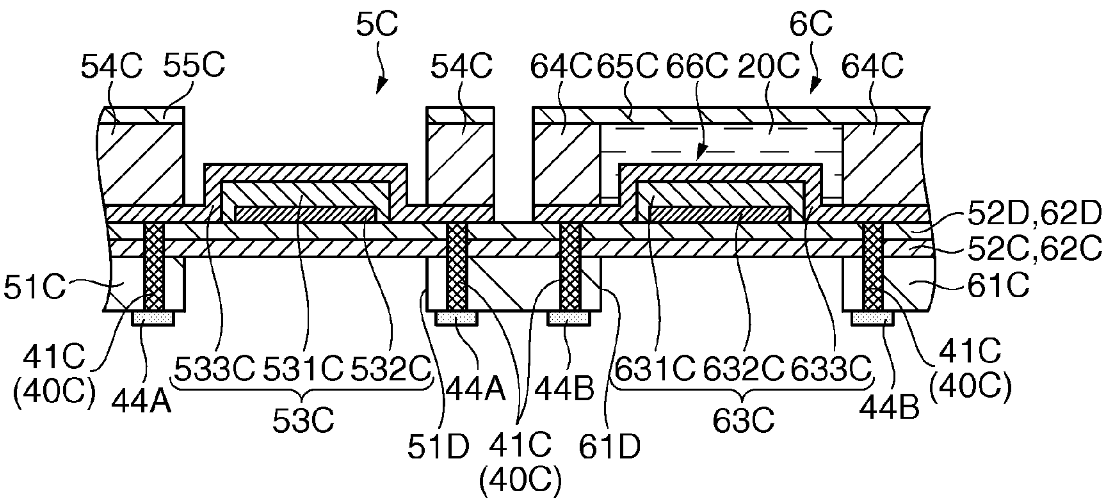

5C
6C
54C
55C
54C
64C
65C
66C
20C
64C
52D,62D
52C,62C
51C
61C
41C
(40C)
44A
533C
531C
532C
53C
44A
44B
51D
41C
(40C)
61D
631C
632C
633C
63C
44B
41C
(40C)

FIG. 28

PRESSURE SENSOR, SENSOR ARRAY, METHOD FOR MANUFACTURING SENSOR ARRAY, AND GRASPING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a divisional patent application of U.S. application Ser. No. 13/105,247 filed May 11, 2011, which claims priority to Japanese Patent Application Nos. 2011-069518 filed Mar. 28, 2011 and 2011-104095 filed May 9, 2011 all of which are expressly incorporated by reference herein in their entireties.

BACKGROUND

1. Technical Field

The present invention relates to a pressure sensor, a sensor array, a method for manufacturing a sensor array, and a grasping apparatus.

2. Related Art

Diaphragm-type ultrasonic sensor devices have been known in the related art (for example, refer to JP-A-2006-319945).

This type of ultrasonic sensor device includes a semiconductor substrate having an opening, two layers of electrodes on an insulating film formed on the surface of the semiconductor substrate to close the opening, and a PZT ceramic thin film layer (piezoelectric film) interposed between the two layers of electrodes. Then, a membrane which has a diaphragm with a multilayer film structure stacked in a planar manner with respect to the opening and a piezoelectric body configured of the piezoelectric film and the two layers of electrodes is formed. In the ultrasonic sensor device, when a predetermined voltage is applied from the upper and lower electrodes to the PZT ceramic thin film layer, the PZT ceramic thin film layer expands and contracts in its in-plane direction, and accordingly, the diaphragm deflects and vibrates in a direction perpendicular to the plane direction to output ultrasonic waves.

In JP-A-2006-319945, a portion of the PZT ceramic thin film layer is exposed to the outside.

It has been generally known that such an ultrasonic sensor device can be applied to a pressure sensor.

For example, in the case where the pressure sensor is applied to a grasping apparatus which grasps an object, the pressure sensor detects, based on a deflection state of the piezoelectric body of the membrane, pressure when the object is grasped by arms or the like of the grasping apparatus.

In this case, since the object directly contacts the piezoelectric film exposed to the outside, a force is locally applied to the piezoelectric body or diaphragm of the membrane, causing a problem that the piezoelectric body or diaphragm of the membrane is likely to be broken.

SUMMARY

An advantage of some aspects of the invention is to solve at least a part of the problem described above, and the invention can be realized as the following modes or application examples.

FIRST APPLICATION EXAMPLE

A first application example is directed to a pressure sensor including: a supporting body which has an opening; a pressure detecting portion which includes a supporting film provided on the supporting body and having a diaphragm portion closing the opening, and a piezoelectric body provided on the diaphragm portion and deflecting to output an electric signal; a frame body which has, on the pressure detecting portion, a cylindrical cavity along a film thickness direction of the supporting film, and is formed, in plan view when viewed from the film thickness direction of the supporting film, at a position where a cylindrical inner peripheral wall of the cavity overlaps with an inner peripheral edge of the opening, or outside of the inner peripheral edge of the opening; a sealing film which closes the frame body; and a pressure medium which is filled in an inner space formed of the cylindrical inner peripheral wall of the cavity, the sealing film, and the pressure detecting portion.

According to this configuration, a portion of the supporting film where the opening is closed serves as the diaphragm portion which detects pressure, and the diaphragm portion and the piezoelectric body stacked on the diaphragm portion form a membrane. That is, in the cavity of the frame body formed on the pressure detecting portion, a portion (membrane) of the pressure detecting portion is contained.

The piezoelectric body of the pressure detecting portion is contained in the frame body, and a pressure medium which disperses a force is filled in the inner space of the frame body. The frame body is sealed by the sealing film.

Therefore, when the pressure sensor is applied to a grasping apparatus which grasps an object, the pressure generated between the sealing film and the object is transmitted to the piezoelectric body via the pressure medium. That is, the object does not directly contact the piezoelectric body, and a force when the object contacts the sealing film is transmitted to the pressure detecting portion via the pressure medium. Thus, the dispersed force is applied to the diaphragm portion of the pressure detecting portion which detects pressure. Accordingly, the local application of force to the diaphragm portion can be prevented, the breakage of the pressure detecting portion can be prevented, and further, the breakage of the membrane can be prevented. The term "on" as used herein means that a specific member is positioned in a direction from the supporting body toward the supporting film, which also includes such a case that specific members are not in contact with each other.

SECOND APPLICATION EXAMPLE

A second application example is directed to the pressure sensor according to the application example, wherein the frame body has flexibility.

According to the application example, since the frame body has flexibility, the frame body contracts when a force is applied to the frame body. Therefore, since the force is transmitted to the diaphragm portion via the pressure medium filled in the inner space of the frame body, pressure can be favorably detected.

THIRD APPLICATION EXAMPLE

A third application example is directed to a sensor array including a plurality of the pressure sensors according to the application example arranged therein, wherein a gap is formed between frame bodies of the pressure sensors next to each other.

According to the application example, a gap is formed between the frame bodies of the pressure sensors. As the gap, for example, a width is set such that the frame bodies contact each other at a value less than a deformation limit of the pressure sensor. When the pressure sensor deforms with pressure, and before the pressure sensor deforms at a value equal to or greater than the deformation limit, the pressure sensor contacts the frame body of the next pressure sensor. Then, since the frame bodies of the pressure sensors function as each other's reinforcing materials, the reliability (resistance to pressure) of the sensor array can be enhanced.

FOURTH APPLICATION EXAMPLE

A fourth application example is directed to a sensor array, including: the pressure sensor described above; and an ultrasonic sensor which has a second supporting body having a second opening, and an ultrasonic transducer portion including a second supporting film which is provided on the second supporting body and has a second diaphragm portion closing the second opening, and a second piezoelectric body which is provided on the second diaphragm portion and deflects by the application of voltage.

According to the application example, the sensor array includes two kinds of sensors, the pressure sensor and the ultrasonic sensor. Therefore, by applying the sensor array according to the application example of the invention to arms or the like of a grasping apparatus which grasps an object for example, the object can be recognized by the ultrasonic sensor, and pressure in a state where the object is grasped by the arms or the like can be detected by the pressure sensor.

The frame body of the ultrasonic sensor can be formed in the same step as that of the frame body constituting the pressure sensor. Since it is only necessary for the ultrasonic sensor to be configured of constituent members excepting a pressure medium and a sealing film, the ultrasonic sensor can be easily manufactured. That is, the ultrasonic sensor can be manufactured in the course of manufacturing the pressure sensor. Accordingly, manufacturing steps of the sensor array can be simplified, which can reduce the manufacturing cost.

FIFTH APPLICATION EXAMPLE

A fifth application example is directed to the sensor array according to the application example, wherein the ultrasonic sensor further includes a second frame body which has, on the ultrasonic transducer portion, a cylindrical second cavity along a film thickness direction of the second supporting film, and is formed, in plan view when viewed from the film thickness direction of the second supporting film, at a position where a cylindrical inner peripheral wall of the second cavity overlaps with an inner peripheral edge of the second opening, or outside of the inner peripheral edge of the second opening.

According to the application example, in the sensor array, the ultrasonic sensor includes the second frame body. Therefore, when the sensor array is applied to arms or the like of a grasping apparatus which grasps an object for example, the deterioration or breakage of the ultrasonic sensor due to contact with the object can be prevented.

SIXTH APPLICATION EXAMPLE

A sixth application example is directed to the sensor array according to the application example, wherein the sensor array includes a plurality of the pressure sensors and a plurality of the ultrasonic sensors, and a gap is formed between frame bodies of the pressure sensors next to each other, between second frame bodies of the ultrasonic sensors next to each other, or between a frame body of the pressure sensor and a second frame body of the ultrasonic sensor next to each other.

According to the application example, the ultrasonic sensor and the pressure sensor are next to each other via a gap. Therefore, the transmission of vibrations of the second diaphragm portion of the ultrasonic sensor is suppressed by the gap portion. Therefore, since the vibrations from the ultrasonic sensor reach the pressure sensor in an attenuated state, it is possible to provide a sensor array which can detect pressure with good accuracy.

SEVENTH APPLICATION EXAMPLE

A seventh application example is directed to the sensor array according to the application example, wherein the supporting body and the second supporting body are a common supporting body which is common to them, and a height from the common supporting body to a top of the pressure sensor is higher than a height from the common supporting body to a top of the ultrasonic sensor.

According to the application example, the top of the pressure sensor serves as an abutment surface. That is, since the top of the pressure sensor abuts on an object prior to the top of the ultrasonic sensor, the top of the ultrasonic sensor does not contact the object in this state. Therefore, the ultrasonic sensor can escape deterioration due to pressure and can maintain high reliability (resistance to pressure).

EIGHTH APPLICATION EXAMPLE

An eighth application example is directed to the sensor array according to the application example, wherein the pressure sensors and the ultrasonic sensors have a two-dimensional array structure in which the pressure sensor and the ultrasonic sensor are alternately arranged.

According to the application example, since the pressure sensors and the ultrasonic sensors have a two-dimensional array structure in which the pressure sensor and the ultrasonic sensor are alternately arranged, a position at which the ultrasonic sensor recognizes an object and a position at which the pressure sensor detects a force grasping the object are substantially the same position of the object. Therefore, position control by the ultrasonic sensor and pressure control by the pressure sensor can be smoothly switched from one to the other.

NINTH APPLICATION EXAMPLE

A ninth application example is directed to the sensor array according to the application example, wherein a dimension of the gap is set such that when a first pressure is applied to the pressure sensor, the frame body deforms to contact the frame body of the next pressure sensor or contact the second frame body of the next ultrasonic sensor, and the first pressure is smaller than an allowable pressure of the pressure sensor.

According to the application example, a gap is formed between the pressure sensors next to each other, between the ultrasonic sensors next to each other, or between the pressure sensor and the ultrasonic sensor next to each other. In this case, the dimension of the gap is set such that when the frame body of the pressure sensor is deformed by a first pressure, the frame body contacts the frame body of the next pressure sensor or the second frame body of the next ultrasonic sensor in a state less than the allowable pressure of the pressure sensor. Then, since the frame body contacts the frame body of the pressure sensor or the second frame body of the ultrasonic sensor with the first pressure in the range of the allowable pressure of the pressure sensor, the frame bodies function as each other's reinforcing materials. Therefore, the reliability (resistance to pressure) of the sensor array can be enhanced. The term "allowable pressure" as used herein means a maximum pressure by which the diaphragm portion or the second diaphragm portion of the pressure sensor or the ultrasonic sensor is not broken.

TENTH APPLICATION EXAMPLE

A tenth application example is directed to a method for manufacturing a sensor array including a plurality of pressure sensors, including: forming a supporting film on a supporting body and forming a piezoelectric body on the supporting film to thereby form a plurality of pressure detecting portions; forming, on the plurality of pressure detecting portions, a frame body layer which covers the piezoelectric body; removing portions of the frame body layer formed in the forming of the frame body layer to thereby form frame bodies each of which includes a cavity having a cylindrical inner peripheral wall so as to have a gap between frame bodies next to each other; filling a pressure medium in the cavity; and forming, by a roll coating method, a sealing film which closes the cavity to seal the pressure medium.

According to this configuration, a sensor array including a plurality of pressure sensors defined with a gap can be manufactured. A dimension of the gap is set such that when the frame body of the pressure sensor is deformed, the frame body contacts the frame body of the next pressure sensor in a state less than an allowable pressure of the pressure sensor, whereby it is possible to form frame bodies which use the frame bodies of the pressure sensors as each other's reinforcing materials in a range of the allowable pressure of the pressure sensor. By providing the gap, it is possible to provide a method for manufacturing a sensor array in which interference from the next pressure sensor can be suppressed.

ELEVENTH APPLICATION EXAMPLE

An eleventh application example is directed to the method for manufacturing the sensor array according to the application example, further including forming a groove which divides the supporting film at a position overlapping with the gap in plan view when the supporting film is viewed from a film thickness direction thereof.

According to the application example, it is possible to avoid interference between the pressure sensors. Since the pressure sensors are connected to each other via the groove, and therefore, interference is suppressed, it is possible to provide a method for manufacturing a sensor array which can detect pressure with high accuracy.

TWELFTH APPLICATION EXAMPLE

A twelfth application example is directed to the method for manufacturing the sensor array according to the application example, further including: bonding a sensor substrate to the lower side of the supporting body; and forming, while leaving at least a portion of the sensor substrate, a groove which divides the supporting body in the gap.

According to the application example, it is possible to provide a method for manufacturing a sensor array which avoids interference between the pressure sensors. Since a groove formed by removing the supporting body is formed between the pressure sensors, the pressure sensors do not interfere with each other, making it possible to provide a method for manufacturing a sensor array which can detect pressure with high accuracy. The term "lower side" as used herein means a direction opposite to the direction indicated by the "on" described above.

THIRTEENTH APPLICATION EXAMPLE

A thirteenth application example is directed to the method for manufacturing the sensor array according to the application example, further including: dividing, after the forming of the sealing film, the sensor array into blocks each of which includes one or more the pressure sensors; and bonding the block to a sensor substrate such that the lower side of the pressure sensor is positioned on the sensor substrate side.

According to the application example, since the pressure sensors are once divided and then bonded to the sensor substrate, the application example can deal with a sensor substrate larger than a supporting body.

FOURTEENTH APPLICATION EXAMPLE

A fourteenth application example is directed to a method for manufacturing a sensor array including a plurality of pressure sensors and a plurality of ultrasonic sensors, including: forming a supporting film on a supporting body and forming a piezoelectric body on the supporting film to thereby form a plurality of pressure detecting portions and a plurality of ultrasonic transducer portions; forming, on the plurality of pressure detecting portions and the plurality of ultrasonic transducer portions, a frame body layer which covers the piezoelectric body; removing portions of the frame body layer formed in the forming of the frame body layer to thereby form a plurality of frame bodies which are defined by a gap and each of which includes a cavity having a cylindrical inner peripheral wall; filling a pressure medium in some of the cavities; and forming, by a roll coating method, a sealing film which closes the cavity to seal the pressure medium.

According to this configuration, a sensor array including a plurality of pressure sensors and a plurality of ultrasonic sensors which are defined with a gap can be manufactured. A dimension of the gap is set such that when the frame body of the pressure sensor is deformed, the frame body contacts the next pressure sensor or the second frame body of the next ultrasonic sensor in a state less than an allowable pressure of the pressure sensor, whereby it is possible to provide a method for manufacturing frame bodies which use the frame body of the pressure sensor or the second frame body of the ultrasonic sensor as each other's reinforcing materials in the range of the allowable pressure of the pressure sensor. Moreover, by providing the gap, it is possible to provide a method for manufacturing a sensor array in which interference from the next pressure sensor or ultrasonic sensor can be suppressed.

FIFTEENTH APPLICATION EXAMPLE

A fifteenth application example is directed to the method for manufacturing the sensor array according to the application example, further including forming a groove which divides the supporting film at a position overlapping with the gap in plan view when the supporting film is viewed from a film thickness direction thereof.

According to the application example, the ultrasonic sensor and the pressure sensor are formed so as to be next to each other via a groove formed by removing the supporting film. Therefore, the vibrations of the second diaphragm portion of the ultrasonic sensor are absorbed by the groove portion. That is, since the vibrations from the ultrasonic sensor reach the pressure sensor in an attenuated state, it is possible to provide a method for manufacturing a sensor array including a pressure sensor which can detect pressure with good accuracy.

SIXTEENTH APPLICATION EXAMPLE

A sixteenth application example is directed to the method for manufacturing the sensor array according to the application example, further including: bonding a sensor substrate to the lower side of the supporting body; and forming, while leaving at least a portion of the sensor substrate, a groove which divides the supporting body at a position overlapping with the gap in plan view when the supporting film is viewed from a film thickness direction thereof.

According to the application example, it is possible to provide a manufacturing method by which interference between the pressure sensors or the ultrasonic sensors can be avoided. Since the pressure sensors or the ultrasonic sensors are formed by mechanically dividing them including the supporting body, they do not interfere with each other, making it possible to provide a method for manufacturing a sensor array which can detect pressure with high accuracy.

SEVENTEENTH APPLICATION EXAMPLE

A seventeenth application example is directed to the method for manufacturing the sensor array according to the application example, further including: dividing, after the forming of the sealing film, the sensor array into blocks each of which includes one or more the pressure sensors or the ultrasonic sensors; and bonding the block to a sensor substrate such that the lower side of the pressure sensor is positioned on the sensor substrate side.

According to the application example, since the ultrasonic sensors or the pressure sensors are once divided and then bonded to the sensor substrate, the application example can deal with a sensor substrate larger than a supporting body.

EIGHTEENTH APPLICATION EXAMPLE

An eighteenth application example is directed to a grasping apparatus including the sensor array described above and grasping an object, including: a pair of grasping arms which grasp the object and each of which is provided with at least one the sensor array on a contact surface with which the object contacts; a grasp detecting unit which detects a grasping state of the object based on an electric signal output from the sensor array; and a drive control unit which controls the driving of the grasping arms based on the grasping state.

According to this configuration, when an object is away from the grasping arms, the driving speed of the grasping arms is increased for operation, whereby the time until the grasping arms approach the object can be shortened. When the object is close to the grasping arms, the driving speed of the grasping arms is reduced, whereby a collision between the grasping arms and the object can be avoided. After the contact of the object with the grasping arms, grasping pressure can be adjusted using a signal from the pressure sensor. That is, it is possible to provide a grasping apparatus which can grasp an object with precise grasping pressure in a short time.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

FIG. **1** is a schematic view of a grasping apparatus.

FIG. **2** is a perspective view showing a sensor array.

FIGS. **3**A and **3**B are cross-sectional views showing an ultrasonic sensor and a pressure sensor, respectively.

FIGS. **4**A to **4**C show manufacturing steps of the sensor array.

FIGS. **5**A to **5**C show manufacturing steps of the sensor array.

FIGS. **6**A to **6**C show manufacturing steps of the sensor array.

FIGS. **7**A and **7**B show manufacturing steps of the sensor array.

FIG. **8** shows a modified example according to a first embodiment.

FIG. **9** is a perspective view showing a sensor array.

FIGS. **10**A, **10**B, and **10**C are a plan view and cross-sectional views, respectively, showing the sensor array.

FIGS. **11**A to **11**H are step cross-sectional views for explaining manufacturing steps of the sensor array.

FIGS. **12**A to **12**D are step cross-sectional views for explaining manufacturing steps of the sensor array.

FIG. **13** is a perspective view showing a sensor array.

FIGS. **14**A and **14**B are a plan view and a cross-sectional view, respectively, showing the sensor array.

FIGS. **15**A and **15**B are cross-sectional views when pressure is applied to the sensor array.

FIGS. **16**A to **16**G are step cross-sectional views for explaining manufacturing steps of the sensor array.

FIGS. **17**A to **17**D are step cross-sectional views for explaining manufacturing steps of the sensor array.

FIG. **18** is a perspective view showing a sensor array.

FIGS. **19**A, **19**B, and **19**C are a plan view and cross-sectional views, respectively, showing the sensor array.

FIG. **20** is a perspective view showing a sensor array.

FIGS. **21**A and **21**B are a plan view and a cross-sectional view, respectively, showing the sensor array.

FIG. **22** is a block diagram for explaining a grasping operation of the grasping apparatus.

FIG. **23** is a flowchart for explaining the grasping operation of the grasping apparatus.

FIGS. **24**A to **24**C are timing diagrams for explaining the grasping operation of the grasping apparatus.

FIG. **25** is a cross-sectional view showing a sensor array.

FIG. **26** shows a manufacturing step of the sensor array.

FIGS. **27**A to **27**C show manufacturing steps of the sensor array.

FIG. **28** is a cross-sectional view showing the sensor array.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

Hereinafter, embodiments according to the invention will be described based on the drawings.

First Embodiment

Schematic Configuration of Grasping Apparatus

FIG. **1** is a schematic view of a grasping apparatus **1**.

The grasping apparatus **1** is an apparatus which grasps, for example, an object **10**. The grasping apparatus **1** recognizes the position of the object **10** to grasp the object. The grasping apparatus **1** includes a supporting member **2** and a pair of arms **3** as grasping arms which extend from the supporting member **2**.

The supporting member **2** is formed in a longitudinal rod shape and includes a drive mechanism which moves the pair of arms **3** toward and/or away from each other.

The arms **3** are portions which grasp the object **10** and operate in directions toward and/or away from each other. At a portion of the arm **3** with which the object **10** contacts, a substantially rectangular grasping surface **31**, for example, is formed. A sensor array **4** (refer to FIG. **2**) is attached to the grasping surface **31**.

Configuration of Sensor Array

FIG. **2** is a perspective view showing a sensor array including ultrasonic sensors and pressure sensors. FIG. **7**B is a step cross-sectional view showing a manufacturing step of the sensor array and is also a cross-sectional view showing the structure of the sensor array shown, in FIG. **2**, which includes a common supporting body **51**, **61** supporting the ultrasonic sensors **5** and the pressure sensors **6**.

The sensor array **4** shown in FIG. **7**B has the common supporting body **51**, **61** in which the supporting body **61** provided with the pressure sensor and the second supporting body **51** provided with the ultrasonic sensor are used in common. The sensor array **4** includes the plurality of ultrasonic sensors **5** and the plurality of pressure sensors **6** which are mounted on the common supporting body **51**, **61**. Moreover, in the sensor array **4**, the ultrasonic sensors **5** and the pressure sensors **6** have a two-dimensional array structure in which the ultrasonic sensor **5** and the pressure sensor **6** are alternately arranged along, for example, a predetermined first direction (X-direction) and a second direction (Y-direction) perpendicular to the first direction (X-direction).

The ultrasonic sensor **5** and the pressure sensor **6** are provided on the common supporting body **51**, **61** which is provided in common to the ultrasonic sensor **5** and the pressure sensor **6**, and are electrically conducted to a not-shown control portion via an electrode pattern which is formed on the common supporting body **51**, **61**. A gap is provided between second frame bodies **54**, between frame bodies **64**, and between the second frame body **54** and the frame body **64**.

In the following description, the common supporting body **51**, **61** will be described while being appropriately separated into the supporting body **61** and the second supporting body **51**.

The term "on" as used herein means that a specific member is positioned in a direction from the common supporting body **51**, **61** toward the frame body **64** and the second frame body **54**, which also includes such a case that specific members are not in contact with each other.

Configuration of Ultrasonic Sensor

FIG. **3**A is a cross-sectional view showing the configuration of the ultrasonic sensor **5**.

The ultrasonic sensor **5** transmits ultrasonic waves to the object **10** and receives reflected waves, thereby detecting the presence or absence of the object **10**, or the distance to the object **10**. The ultrasonic sensor **5** includes a second supporting film **52**, a second piezoelectric body **53**, the second frame body **54**, and a protective film **55** which are stacked in order on the second supporting body **51**.

The second supporting film **52** and the second piezoelectric body **53** constitute an ultrasonic transducer portion **11**.

The second supporting body **51** is formed of a single-crystal silicon substrate and formed to a thickness of about 200 μm. Moreover, in the second supporting body **51**, a circular second opening **51**A, in plan view when the second supporting film **52** is viewed from its film thickness direction, is formed by dry etching.

The second supporting film **52** closes the second opening **51**A of the second supporting body **51**, is configured of a first oxide film **52**A and a second oxide film **52**B which are stacked on the surface of the second supporting body **51**, and is formed of the two layers. A portion of the second supporting film **52** where the second opening **51**A is closed serves as a second diaphragm portion **57**. The second diaphragm portion **57** and the second piezoelectric body **53** which is provided on the second diaphragm portion **57** and deflects by the application of voltage constitute a membrane **8**.

The first oxide film **52**A is formed of, for example, SiO_2 and formed to a thickness of about 1 μm by thermally oxidizing the surface of the single-crystal silicon substrate of the second supporting body **51**. The first oxide film **52**A may be formed by, other than the thermal oxidation of the surface, a chemical vapor deposition (CVD) method using tetraethoxysilane (TEOS), sputtering, vapor deposition, coating, or the like.

The second oxide film **52**B is formed of, for example, ZrO_2 and formed on the first oxide film **52**A so as to finally have a thickness of about 3 μm by depositing Zr by sputtering and thermally oxidizing the same. The second oxide film **52**B is a layer for preventing the peeling of a later-described second piezoelectric film **531** of the second piezoelectric body **53** when the second piezoelectric film **531** is formed by baking. That is, when the second piezoelectric film **531** (for example, lead zirconate titanate (PZT)) is baked, in the case where the second oxide film **52**B is not formed, Pb is diffused in the first oxide film **52**A. Therefore, the melting point of the second oxide film **52**B is lowered, and air bubbles are generated on the surface of the first oxide film **52**A, whereby the second piezoelectric film **531** is peeled due to the air bubbles. Moreover, when the second oxide film **52**B is not present, there also arises a problem that the deflection efficiency to the strain of the second piezoelectric film **531** is reduced. On the other hand, by forming the second oxide film **52**B on the first oxide film **52**A, inconveniences such as the peeling of the second piezoelectric film **531** or the decrease in deflection efficiency can be avoided. The second oxide film **52**B may be formed by a CVD method, vapor deposition, coating, or the like other than a sputtering method.

In this case, a diameter dimension D' of the second opening **51**A is appropriately set in a range from, for example, about one hundred μm to several hundreds μm according to the natural frequency of the second diaphragm portion **57**. The second diaphragm portion **57** vibrates, so that ultrasonic waves are transmitted toward the object **10** (refer to FIG. **1**) side.

The second piezoelectric body **53** is a film-like member which is formed concentrically with the second opening **51**A in plan view of the sensor. The diameter dimension of the second piezoelectric body **53** is smaller than the diameter dimension D' of the second opening **51**A. The second piezoelectric body **53** includes the second piezoelectric film **531** and electrodes (a lower electrode **532** and an upper electrode **533**) which apply voltage to the second piezoelectric film **531**. The term "diameter dimension of piezoelectric body" as used herein means the diameter of a region where the lower electrode, the piezoelectric film, and the upper electrode are stacked.

The piezoelectric film **531** is formed of, for example, PZT made into a film. Although, in the embodiment, PZT is used as the piezoelectric film **531**, any material may be used as long as the material can contract and expand in an in-plane direction by the application of voltage. For example, lead titanate ($PbTiO_3$), lead zirconate ($PbZrO_3$), lead lanthanum titanate ($(Pb, La)TiO_3$), or the like may be used.

The lower electrode **532** and the upper electrode **533** are electrodes which are formed with the piezoelectric film **531** interposed therebetween.

The lower electrode **532** is formed below the second piezoelectric film **531**. The upper electrode **533** is formed on the second piezoelectric film **531**.

The upper electrode **533** and the lower electrode **532** are drawn through a not-shown drawing portion which is formed on the back side (the second opening **51**A side) of the second diaphragm portion **57**, are connected to the not-shown control portion of the sensor array **4**, and apply a predetermined voltage to the piezoelectric film **531** based on a voltage signal input from the control portion.

The second frame body **54** is cylindrically formed of a permanent resist made of a synthetic resin material having flexibility and formed to a thickness of about 100 μm to 600 μm. Moreover, with a cylindrical inner peripheral wall **541** provided in the second frame body **54**, a cavity **54**A along the film thickness direction of the second supporting film **52** is formed. The second frame body **54** is formed such that in plan view when viewed from the film thickness direction of the second supporting film **52**, a cylindrical inner peripheral edge of the cavity **54**A which is cylindrical is positioned to be overlapped with an inner peripheral edge of the second opening **51**A or positioned outside of the inner peripheral edge. In this case, the inner diameter dimension of the second frame body **54** is formed so as to have substantially the same dimension as that of the second opening **51**A (in the case of overlapping). In the cavity **54**A of the second frame body **54**, the membrane **8** is contained. For example, the second frame body **54** can be formed using permanent resist TMMR™ S2000 of TOKYO OHKA KOGYO CO., LTD.

As the material for forming the second frame body **54**, a photosensitive resin film such as of a dry film resist may be used other than a permanent resist.

The protective film **55** is a portion which contacts the object **10**, is formed of a dry film resist made of a synthetic resin material having flexibility, similarly to the second frame body **54**, and is formed to a thickness of about 100 μm. Moreover, the protective film **55** is formed in a ring shape to cover an upper end surface of the second frame body **54**. For example, the protective film **55** can be formed using dry film resist TMMF™ S2000 of TOKYO OHKA KOGYO CO., LTD.

Operation of Ultrasonic Sensor

In the ultrasonic sensor **5** described above, when a drive voltage having a predetermined cycle is applied from the control portion between the lower electrode **532** and the upper electrode **533** of the second piezoelectric body **53**, the piezoelectric film **531** expands or contracts in its plane direction.

When the piezoelectric film **531** contracts in the plane direction, the second piezoelectric body **53** side of the second diaphragm portion **57** is contracted in the plane direction, so that the second diaphragm portion **57** convexly deflects toward the second supporting body **51** side. When the piezoelectric film **531** expands in the plane direction, the second piezoelectric body **53** side of the second diaphragm portion **57** is expanded in the plane direction, so that the second diaphragm portion **57** convexly deflects toward the second piezoelectric body **53** side.

Thus, the second diaphragm portion **57** vibrates in a direction perpendicular to the plane direction of the second supporting film **52**, and ultrasonic waves at a frequency according to the predetermined drive voltage cycle is transmitted from the second diaphragm portion **57**. That is, the second diaphragm portion **57** functions as a transmitting portion which transmits ultrasonic waves toward the object **10** (refer to FIG. **1**). Further, the second diaphragm portion **57** also functions as a receiving portion which receives ultrasonic waves reflected by the object **10**. That is, in the control portion of the sensor array **4**, the position of the object **10** can be detected based on the time from the transmission of ultrasonic waves to the reception of ultrasonic waves reflected by the object **10** and the intensity of vibrations.

Configuration of Pressure Sensor

FIG. **3**B is a cross-sectional view showing the pressure sensor **6**.

The pressure sensor **6** detects pressure when, for example, the grasping surfaces **31** of the arms **3** of the grasping apparatus **1** (refer to FIG. **1**) grasp the object **10**. The pressure sensor **6** provided on the grasping surface **31** includes a supporting film **62**, a piezoelectric body **63** (a piezoelectric film **631**, a lower electrode **632**, and an upper electrode **633**), the frame body **64**, and a sealing film **65** which are stacked in order on the supporting body **61**.

In this case, the supporting body **61** is a common supporting body which is common with the second supporting body **51** of the ultrasonic sensor **5**, and the configurations of the supporting film **62**, the piezoelectric body **63**, and the frame body **64** are similar to those of the second supporting film **52**, the second piezoelectric body **53**, and the second frame body **54** of the ultrasonic sensor **5**, respectively. Therefore, the description is omitted.

The supporting film **62** and the piezoelectric body **63** constitute a pressure detecting portion **9**.

The frame body **64** is formed cylindrically, similarly to the second frame body **54** of the ultrasonic sensor **5**, and has a cavity **64**A. In the cavity **64**A, the membrane **8** including a diaphragm portion **67** which is a portion of the supporting film **62** where an opening **61**A is closed and the piezoelectric body **63** provided on the diaphragm portion **67** is contained.

A silicone oil **20** as a pressure medium is filled in an inner space **66** formed of a cylindrical inner peripheral wall **641** of the cavity **64**A, the sealing film **65**, and the pressure detecting portion **9**.

The sealing film **65** closes the inner space **66** to seal the silicone oil **20**. As the material to be filled in the inner space **66**, any material which disperses pressure may be used. Other than the silicone oil **20**, for example, a silicone rubber, a polymer gel, a synthetic gel, a natural gel, a polymer resin, or the like may be used. The frame body **64** is formed such that in plan view when viewed from the film thickness direction of the supporting film **62**, a cylindrical inner peripheral edge of the cavity **64**A which is cylindrical is positioned to be overlapped with an inner peripheral edge of the opening **61**A or positioned outside of the inner peripheral edge. In this case, the inner diameter dimension of the frame body **64** is formed so as to have substantially the same dimension as a diameter dimension D of the opening **61**A (in the case of overlapping).

The sealing film **65** is a portion which contacts the object **10** (refer to FIG. **1**), similarly to the protective film **55**, and is formed in a circular shape so as to close the inner space **66** to seal the silicone oil **20**. Moreover, the sealing film **65** is a portion which seals the silicone oil **20** and contacts the object **10**. The sealing film **65** is formed of a material similar to that of the protective film **55**. For example, the sealing film **65** can be formed using dry film resist TMMF™ S2000 of TOKYO OHKA KOGYO CO., LTD.

As the material for forming the sealing film **65**, a photosensitive resin film such as of a permanent resist may be used other than a dry film resist.

Since the silicone oil **20** is filled in the inner space **66**, an impact when the object **10** contacts the sealing film **65** is dispersed over the entire membrane **8**.

When a pressure medium filled in the inner space **66** is a material which does not leak, such as a polymer gel, the sealing film **65** may not be provided.

Operation of Pressure Sensor

In the pressure sensor **6** described above, when the object **10** is grasped by the arms **3** as shown in FIG. **1**, the object **10** abuts on the sealing film **65** shown in FIG. **3**B, and the frame body **64** contracts in the thickness direction. In this case, the silicone oil **20** filled in the inner space **66** of the frame body **64** disperses a force when the object **10** abuts on the sealing film **65** over the entire membrane **8**, and the force is transmitted to the diaphragm portion **67**. The diaphragm portion **67** deflects with the transmitted force, and voltage according to the deflection amount is generated in the piezoelectric film **631**. Thus, an electric signal according to the generated voltage is output from the upper electrode **633** and the lower electrode **632**, whereby pressure is detected.

Method for Manufacturing Sensor Array

Next, a method for manufacturing a sensor array will be described.

FIGS. **4**A to **7**B are step cross-sectional views showing manufacturing steps of a sensor array having the structure. In FIGS. **4**A to **7**B, manufacturing steps of the ultrasonic sensor **5** are shown on the left while manufacturing steps of the pressure sensor **6** are shown on the right.

In the following description, a pair of ultrasonic sensor **5** and pressure sensor **6** are described. However, this is applicable also to the case of a plurality of ultrasonic sensors **5** and a plurality of pressure sensors **6** (refer to FIG. **2**).

First, a single-crystal silicon substrate which serves as the common supporting body **51**, **61** (a thickness of about 650 μm) where the opening **61**A and the second opening **51**A are not formed is prepared, and the surface of the substrate is thermally oxidized, whereby the first oxide film **52**A, **62**A formed of SiO_2 is formed so as to have a thickness of about 1 μm. Using ZrO_2 formed by depositing Zr by sputtering and thermally oxidizing the same, the second oxide film **52**B, **62**B is formed on the first oxide film **52**A, **62**A so as to have a thickness of about 3 μm. FIG. **4**A shows the cross-sectional view in a state where the step so far is completed.

Next, in an argon gas atmosphere under a predetermined pressure, a substance for lower electrode is deposited by sputtering on the second oxide film **52**B, **62**B. A not-shown photoresist is coated on a surface where the common supporting film **52**, **62** is formed so as to be stacked on the common supporting body **51**, **61**, and exposed and developed by a photolithography method. Further by an etching process, the lower electrodes **532** and **632** are patterned. In this case, any value can be taken for a gap between the lower electrodes **532** and **632** as long as the electrodes are not in contact with each other. FIG. **4**B shows the cross-sectional view in a state where the steps so far are completed.

Next, a substance for the piezoelectric films **531** and **631** is deposited by sputtering on the lower electrodes **532** and **632**. By patterning by a photolithography method and an etching process, the piezoelectric films **531** and **631** are formed. FIG. **4**C shows the cross-sectional view in a state where the steps so far are completed.

Next, a substance for the upper electrodes **533** and **633** is deposited by sputtering so as to cover the lower electrodes **532** and **632** and the second oxide film **52**B, **62**B. By patterning by a photolithography method and an etching process, the upper electrodes **533** and **633** are formed. Thus, the ultrasonic transducer portion **11** and the pressure detecting portion **9** are formed on the ultrasonic sensor **5** side and the pressure sensor **6** side, respectively (piezoelectric body sensor portion forming step). FIG. **5**A shows the cross-sectional view in a state where the steps so far are completed.

Next, the common supporting body **51**, **61** is grinded so that the thickness is reduced to about 200 μm. This is because when the common supporting body **51**, **61** which has been grinded to a desired thickness dimension is prepared in the first step, the common supporting body **51**, **61** may be warped during the manufacturing steps. FIG. **5**B shows the cross-sectional view in a state where the steps so far are completed.

Next, a permanent resist is coated as a frame body layer **70** on the upper electrodes **533** and **633** using a spin coating apparatus or a squeegee. Thus, the frame body layer **70** is formed so as to cover the piezoelectric body **63** and the second piezoelectric body **53** (frame body layer forming step). FIG. **5**C shows the cross-sectional view in a state where the steps so far are completed.

Next, the frame body layer **70** coated on the upper electrodes **533** and **633** is exposed and developed by a photolithography method to pattern the frame body layer **70** into a desired shape. In this step, the frame body **64** and the second frame body **54** which have the cavities **54**A and **64**A and are independent of each other are formed (frame body forming step). FIG. **6**A shows the cross-sectional view in a state where the steps so far are completed.

Next, the silicone oil **20** is filled in the cavity **64**A of the frame body **64** of the pressure sensor **6** (filling step). FIG. **6**B shows the cross-sectional view in a state where the steps so far are completed.

Next, a dry film resist corresponding to the protective film **55** and the sealing film **65** is coated on the upper surface of the frame body **64** and the second frame body **54** using a roll coating apparatus (film forming step). With this step, the inner space **66** is formed. FIG. **6**C shows the cross-sectional view in a state where the steps so far are completed.

Next, the dry film resist corresponding to the protective film **55** and the sealing film **65** is exposed and developed by a photolithography method to pattern the protective film **55** and the sealing film **65** into a desired shape. FIG. **7**A shows the cross-sectional view in a state where the steps so far are completed.

Next, the lower surface side of the common supporting body **51**, **61** is dry etched to form the opening **61**A and the second opening **51**A having substantially the same dimensions as the inner diameter dimensions of the frame body **64** and the second frame body **54**.

Through the steps described above, the sensor array **4** including the plurality of ultrasonic sensors **5** and the plurality of pressure sensors **6** on the common supporting body **51**, **61**, shown in FIG. **7**B, is formed.

According to the pressure sensor **6**, the sensor array **4**, and the method for manufacturing the sensor array **4** of the embodiment described above, the following advantageous effects are provided.

As shown in FIG. **3**B, the piezoelectric body **63** of the membrane **8** is contained in the frame body **64**, and the silicone oil **20** which disperses a force is filled in the inner space **66** of the frame body **64**. The frame body **64** is sealed by the sealing film **65**. According to this configuration, when the arms **3** of the grasping apparatus **1** grasp the object **10**, the object **10** abuts on the sealing film **65**, and a force in this state is transmitted to the membrane **8** via the silicone oil **20**. That is, since the object **10** does not directly contact the piezoelectric film **631** and a force when the object **10** contacts the sealing film **65** is transmitted to the membrane **8** via the silicone oil **20**, the dispersed force is applied to the diaphragm portion **67** of the membrane **8** which detects pressure. Accordingly, the local application of force to the diaphragm portion **67** can be prevented, which can prevent the breakage of the membrane **8**.

As shown in FIG. **3**B, since the frame body **64** is formed of a permanent resist made of a synthetic resin having flexibility, the frame body **64** contracts when a force is applied to the frame body **64**. The force is transmitted to the diaphragm portion **67** of the membrane **8** via the silicone oil **20** filled in the inner space **66** of the frame body **64**, so that pressure can be favorably detected.

As shown in FIG. **2**, the sensor array **4** includes two kinds of sensors, the pressure sensor **6** and the ultrasonic sensor **5**. Therefore, the grasping apparatus **1** including the sensor array **4** can recognize the object **10** by the ultrasonic sensor **5** and detect pressure in a state where the arms **3** grasp the object **10** by the pressure sensor **6**.

As shown in the method for manufacturing the sensor array, since it is only necessary for the ultrasonic sensor **5** to be configured of the constituent members constituting the pressure sensor **6** excepting the silicone oil **20** and the sealing film **65**, the ultrasonic sensor **5** can be manufactured easily. That is, the ultrasonic sensor **5** can be manufactured in the course of manufacturing the pressure sensor **6**. Accordingly, the manufacturing steps of the sensor array **4** can be simplified, which can reduce the manufacturing cost.

In the case of configuring a sensor array having a portion where only the pressure sensor **6** is formed or a portion where only the ultrasonic sensor **5** is formed, a position at which the ultrasonic sensor **5** recognizes the object **10** sometimes differs from a position at which the pressure sensor **6** detects a force grasping the object **10**, which may cause a variation between detected positions of the sensors **5** and **6**.

In the embodiment, on the other hand, since the pressure sensors **6** and the ultrasonic sensors **5** are arranged at equal distances from each other as shown in FIG. **2**, a variation does not occur between the position at which the ultrasonic sensor **5** recognizes the object **10** and the position at which the pressure sensor **6** detects the force grasping the object **10**.

Since the ultrasonic sensor **5** and the pressure sensor **6** are arranged independently of each other, the transmission of vibrations of the membrane **8** of the ultrasonic sensor **5** to the pressure sensor **6** can be suppressed. That is, since the influence of vibrations from the ultrasonic sensor **5** on the piezoelectric body **63** or the diaphragm portion **67** of the membrane **8** of the pressure sensor **6** is reduced, the pressure sensor **6** can detect pressure with good accuracy.

Hereinafter, another embodiment (second embodiment) according to the invention will be described based on the drawings.

Second Embodiment

Configuration of Sensor Array

FIG. **9** is a perspective view showing a sensor array **180** according to the second embodiment. FIG. **10**A is a plan view of the sensor array **180** shown in FIG. **9**; FIG. **10**B is a cross-sectional view taken along line A-A' shown in FIG. **10**A when the object **10** contacts the sensor array; and FIG. **10**C is a cross-sectional view taken along the line A-A' when a greater pressure than usual is applied in a state of grasping the object **10**.

The sensor array **180** is, for example, a tactile sensor having excellent resistance to pressure and outputs, as an electric signal, pressure between the object **10** and the sensor array **180** as shown in FIGS. **10**A to **10**C. The sensor array **180** includes a plurality of pressure sensors **106** which are mounted on a supporting body **161**. The sensor array **180** differs from the sensor array of the first embodiment in that a groove G as a gap is arranged so that when a smaller pressure than an allowable pressure of the pressure sensor **106**, near the allowable pressure, is applied, frame bodies of the pressure sensors **106** next to each other are pushed (contacted) to each other to thereby function as each other's reinforcing materials. Other than these points, the sensor array **180** is similar to that described in the first embodiment. For example, the groove G may be formed only at a portion between the pressure sensors **106**.

The pressure sensor **106** has the structure shown in "Configuration of Pressure Sensor" described above. That is, in FIG. **10**B, since a membrane **108** is subjected to pressure via a silicone oil **120** with a top of the pressure sensor **106** being as a pressure-sensitive surface (abutment surface), an impact from the object **10** can be dispersed over the entire membrane **108**. Since the membrane **108** is protected from the concentration of pressure, the reliability of the pressure sensor **106** can be improved.

The pressure sensor **106** performs the operation shown in "Operation of Pressure Sensor" described above. That is, a piezoelectric film **731** deflects by being subjected to pressure from the object **10**, and voltage according to the deflection amount is generated. Thus, the pressure can be detected based on the voltage generated from the membrane **108**.

As shown in FIGS. **9** and **10**B, in the sensor array **180**, the pressure sensors **106** each of which has a frame body **164** whose outer shape is a rectangle (square as an example in this case) are arranged, on a supporting body **161** which includes openings **121** and is provided in common to the plurality of pressure sensors, along a predetermined first direction (X-direction) and a second direction (Y-direction) perpendicular to the first direction (X-direction) with the grooves G all having the same width and each interposed between the pressure sensors. In other words, a gap for separating the frame bodies **164** from each other is formed between the frame bodies.

The width of the groove G will be described in "Operation of Sensor Array" described later.

The pressure sensors **106** are arranged to be separated from each other so that the supporting body **161** is exposed in the gap between the pressure sensors.

Although, in the preferred example shown in FIG. **9**, the groove G is formed to the position of the surface of the supporting body **161**, a structure in which a portion of the supporting body **161** is hollowed may be used. Especially when silicon is used for the supporting body **161** and silicon oxide or ZrO_2 is used for a supporting film **162**, high shape reproducibility can be provided because a high selectivity is obtained when performing etching.

Moreover, a configuration having a groove G formed to such a depth that the supporting film. **162** is exposed may be used. In this case, especially when a permanent resist is used for the frame body **164**, high shape reproducibility can be provided because etching is stopped by the supporting film **162**. Moreover, since etching can be performed using a developer at the same time as when the frame body **164** is fabricated, the manufacturing steps can be shortened.

Moreover, it is allowed for the groove G to use a structure in which a frame body layer **170** made of a permanent resist used for forming the frame body **164** is thinly left at the bottom of the groove on the supporting body side. In this case, a processing method for obtaining the configuration described above is described. However, this does not intend to limit a processing method but is introduced as an example for obtaining the structure. Irrespective of a processing method, it is sufficient to have the shape described above. Moreover, the pressure sensors **106** may be divided into individual ones (edge cutting) and may be arranged again on a sensor substrate (not shown) which is prepared separately. Moreover, a sensor substrate may be bonded to the supporting body **161** and may be cut (edge cutting) to the supporting body **161**. In this case, since interference between the pressure sensors **106** can be prevented, pressure can be measured with higher accuracy.

The term "edge cutting" as used herein includes, in addition to the case of complete separation, the case where the pressure sensors are not completely separated but connected to such an extent that they do not cause functional interference.

Operation of Sensor Array

Next, the operation of the sensor array **180** will be described with reference to FIGS. **1** and **10**A to **10**C. The sensor array **180** (not shown in FIG. **1**) is described as being bonded to the grasping surface **31** in this case.

First, when the object **10** contacts the grasping surface **31** as shown in FIG. **10**B, the pressure sensor **6** detects pressure given to the object **10**. By applying pressure from the grasping surface **31** to the object **10**, the object **10** is grasped.

When too much stress is applied to the pressure sensor **106**, the pressure sensor **106** may be excessively collapsed and deteriorated. When excessive pressure is applied to the pressure sensor **106**, the frame body **164** deforms such that the central portion expands more than both ends with respect to the height direction of the frame body, the region formed by separation with the groove G is filled, and the frame body **164** and the frame body of the next pressure sensors **106** are pushed to each other. As shown in FIG. **10**C, therefore, the pressure sensors **106** next to each other function as each other's reinforcing materials, which can prevent the deterioration of the pressure sensor **106** caused by excessive collapse. In other words, the width of the groove G is preferably such a width that the frame bodies **164** contact each other when pressure less than a breaking strength is applied.

Method for Manufacturing Sensor Array

Next, a method for manufacturing the sensor array **180** including the pressure sensors **106** will be described.

FIGS. **11**A to **12**D are step cross-sectional views for explaining manufacturing steps for manufacturing the plurality of pressure sensors **106**.

First, a single-crystal silicon substrate which serves as the supporting body **161** (a thickness of about 650 μm) is prepared, and the surface of the substrate is thermally oxidized, so that a first oxide film **162**A formed of SiO_2 is formed so as to have a thickness of about 1 μm. By depositing Zr by sputtering and thermally oxidizing the same, ZrO_2 is formed on the first oxide film **162**A. A second oxide film **162**B formed of ZrO_2 is formed so as to finally have a thickness of about 3 μm, whereby the supporting film **162** is formed. FIG. **11**A shows the step cross-sectional view in a state where the step so far is completed.

In this case, when the groove G is formed to a portion of the supporting body **161** between the pressure sensors **106**, a step of forming the groove G is preferably performed in this state where the supporting film **162** is formed, in view of the manufacturing steps. In the embodiment, the case of using, in a later step than this step, the step of forming the groove G by which the supporting body **161** is exposed and the supporting film **162** is divided will be described. The groove G is formed at a position overlapping with the gap between the pressure sensors **106**.

Next, in an argon gas atmosphere under a predetermined pressure, a conductor film constituting a lower electrode **732** is formed so as to cover the second oxide film **162**B using sputtering deposition. A not-shown photoresist is coated on the surface side of the supporting body **161** where the supporting film **162** is formed, and exposed and developed by a photolithography method. Further by an etching process, the lower electrode **732** is patterned.

FIG. **11**B shows the step cross-sectional view in a state where the steps so far are completed.

Next, a film for forming the piezoelectric film **731** is deposited by sputtering so as to cover the lower electrode **732**. By a photolithography method and an etching process, the piezoelectric film **731** is patterned. The piezoelectric film **731** functions as a pressure detecting portion.

FIG. **11**C shows the step cross-sectional view in a state where the steps so far are completed.

Next, on the surface side of the supporting body **161** where the lower electrode **732** is arranged, a conductor film constituting an upper electrode **733** is deposited by a sputtering method. By a photolithography method and an etching process, the upper electrode **733** is patterned to form a plurality of island-like piezoelectric bodies **163**. Thus, island-like pressure detecting portions **175** (including the supporting film **162** and the piezoelectric body **163**) are formed. The term "island-like pressure detecting portion" as used herein means that the shape of a region where four layers of the supporting film, the lower electrode, the piezoelectric film, and the upper electrode are stacked is an independent island-like shape (pressure detecting portion forming step). Next, the groove G which divides the supporting film **162** is formed (groove forming step).

FIG. **11**D shows the step cross-sectional view in a state where the steps so far are completed.

Next, the supporting body **161** is grinded by, for example, back grinding (BG) so that the thickness is reduced to about 200 μm. This is because when the supporting body **161** which has been grinded to a desired thickness dimension is prepared in the steps so far, the supporting body **161** may be warped during the manufacturing steps.

FIG. **11**E shows the step cross-sectional view in a state where the steps so far are completed.

Next, a permanent resist is coated as the frame body layer **170** on the upper electrodes **733** using a spin coating apparatus or a squeegee. Thus, the frame body layer **170** is formed so as to cover the piezoelectric bodies **163** (frame body layer forming step).

FIG. **11**F shows the step cross-sectional view in a state where the steps so far are completed.

If the groove G is formed in a step after forming the frame body layer **170**, the frame body layer **170** may be damaged. Therefore, the groove G is preferably formed in the steps so far. Specifically, the groove G may be processed such that a region whose thickness is thin is provided between the frame bodies **164** next to each other using the same material as the frame body **164**, that a region where the piezoelectric body **163** is exposed is provided between the frame bodies **164** next to each other, that a region where the supporting body **161** is exposed is provided between the frame bodies **164** next to each other (in the case of the embodiment), or that a region where the supporting body **161** is exposed and further the supporting body **161** is hollowed is provided between the frame bodies **164** next to each other. If the damage of the frame body layer **170** can be prevented even when the groove G is formed, the step of forming the groove G may be performed in a later step.

The frame body layer **170** (permanent resist) coated on the upper electrodes **733** is exposed and developed by a photolithography method to pattern the frame body layer **170** such that the outer shape of a region to serve as the frame body **164** of the frame body layer **170** is a rectangle (square as an example in this case) as shown in FIGS. **10**A to **10**C, and to pattern the frame body layer **170** so as to form a cavity **164**A to expose a detecting portion **175** inside the region to serve as the frame body **164**, whereby the plurality of frame bodies

164 are formed (frame body forming step). FIG. 11G shows the step cross-sectional view in a state where the steps so far are completed.

In the cavity 164A of the frame body 164, the silicone oil 120 as a pressure medium is filled (filling step). Any material can be used for this as long as the material disperses pressure. Other than the silicone oil 120, for example, a silicone rubber, a polymer gel, a synthetic gel, a natural gel, a polymer resin, or the like may be used.

FIG. 11H shows the step cross-sectional view in a state where the steps so far are completed.

Next, a dry film resist 165A is coated as a sealing film on the upper surface of the frame body 164 by a roll coating apparatus (film forming step). Thus, the cavity 164A is sealed to serve as an inner space 166. FIG. 12A shows the step cross-sectional view in a state where the steps so far are completed.

In this case, for coating without including air bubbles, coating is preferably performed in a reduced-pressure atmosphere. Moreover, for closely adhering the resist 165A, coating is preferably performed while heating.

Next, patterning is performed so as to leave the resist 165A located at a region overlapping with the frame body 164 and inside the frame body 164, whereby a sealing film 165 as a pressure-sensitive film serving as a pressure-sensitive surface is formed. FIG. 12B shows the step cross-sectional view in a state where the steps so far are completed.

Next, the surface (back surface) of the supporting body 161 where the supporting film 162 is not present is dry etched such that, in plan view of the supporting body 161, an opening is substantially overlapped with an opening inside the frame body 164. Then, an opening 161A is formed so as to substantially overlap with the opening inside the frame body 164. FIG. 12C shows the step cross-sectional view in a state where the steps so far are completed.

By completing the steps so far, the sensor array 180 including the pressure sensors 106 is formed.

In addition to the steps of the manufacturing method described above, a step of bonding a sensor substrate 45D to the supporting body 161, cutting the supporting body 161, and separating the pressure sensors 106 may be added. In this case, a structure shown in FIG. 12D can be obtained. That is, the pressure sensor 106 is supported by the sensor substrate 45D.

Moreover, the supporting body 161 may be first cut and then bonded to the sensor substrate 45D.

According to the configuration of the pressure sensor 106, the configuration of the sensor array 180, and the method for manufacturing the sensor array 180 of the embodiment described above, the following advantageous effects can be obtained.

When excessive pressure is applied to the pressure sensor 106, the frame body 164 deforms such that the central portion expands more than both ends with respect to the height direction of the frame body, the groove G is filled, and the frame body 164 and the frame body of the next pressure sensor 106 are pushed to each other. As shown in FIG. 10C, therefore, the pressure sensors 106 next to each other function as each other's reinforcing materials, which can prevent the deterioration of the pressure sensor 106 caused by excessive collapse.

The pressure sensors 106 each of which has the frame body 164 whose outer shape is a rectangle (square as an example in this case) are arranged along the predetermined first direction (X-direction) and the second direction (Y-direction) perpendicular to the first direction (X-direction) with the grooves G all having the same value. Therefore, when excessive pressure is applied to the pressure sensors 106, the frame bodies 164 next to each other are pushed to each other at a plane. Therefore, compared to the case where the outer shape of the frame body 164 is, for example, circular or the like, since the frame bodies 164 next to each other are pushed to each other at a plane, resistance to high pressure can be further improved, making it possible to provide the sensor array 180 with high reliability.

After performing the manufacturing process to a certain extent, the step of grinding the supporting body 161 by, for example, back grinding (BG) so that the thickness is reduced to about 200 μm is used. Therefore, it is possible to suppress the occurrence of such a defect that the supporting body 61 is warped during the manufacturing steps.

Hereinafter, still another embodiment (third embodiment) according to the invention will be described based on the drawings.

Third Embodiment

Configuration of Sensor Array

FIG. 13 is a perspective view showing a sensor array 281. FIG. 14A is a plan view of the sensor array 281 shown in FIG. 13; and FIG. 14B is a cross-sectional view taken along line A-A' of the plan view shown in FIG. 14A. The sensor array 281 includes ultrasonic sensors 205 in addition to pressure sensors 206.

The sensor array 281 is, for example, a tactile sensor which can detect distance information and pressure information. The sensor array 281 includes the plurality of ultrasonic sensors 205 each of which outputs distance information as an electric signal when the object 10 is away from the sensor array 281, and the plurality of pressure sensors 206 each of which outputs, as an electric signal, the pressure between the object 10 and the sensor array 281 when the object 10 contacts the sensor array 281. The sensor array 281 differs from the sensor array 180 in the second embodiment (for example, refer to FIGS. 10A and 10B) in including the plurality of ultrasonic sensors 205 in addition to the plurality of pressure sensors 206 mounted on a common supporting body 251, 261.

The sensor array 281 has such features that a top of the pressure sensor 206 based on the common supporting body 251, 261 is formed so as to be positioned high compared to a top of the ultrasonic sensor 205, and that the pressure sensor 206 and the ultrasonic sensor 205 are arranged via a groove K as a predetermined gap so that when a smaller pressure than an allowable pressure of the sensor array 281, near the allowable pressure, is applied, the pressure sensor 206 and the ultrasonic sensor 205 are pushed (contacted) to the next pressure sensor 206 or the next ultrasonic sensor 205 to thereby function as each other's reinforcing materials. Other than these points, the sensor array 281 is similar to those described in the first embodiment and the second embodiment. For example, the groove K may be formed only at a portion between the pressure sensor 206 and the ultrasonic sensor 205.

By including the ultrasonic sensor 205, even in a state where the arm 3 of the grasping apparatus 1 (refer to FIG. 1) is away from the object 10, the distance between the arm and the object 10 can be measured. Therefore, it is possible to grasp the object 10 with higher speed and precision. For example, since the distance between the arm and the object 10 can be measured, the arms 3 are moved at high speed until they contact the object 10, and a grasping state is maintained by the pressure sensors 206 after contact, thereby making it possible to grasp the object 10 in a state of maintaining the accuracy of grasping pressure.

The ultrasonic sensor **205** has the structure shown in "Configuration of Ultrasonic Sensor" described above. That is, as shown in FIG. **3**A, the second diaphragm portion **57** which can perform free vibrations is provided, and the piezoelectric film **731** using PZT or the like is connected to the second diaphragm portion **57**. The lower electrode **732** and the upper electrode **733** which apply voltage to the piezoelectric film **731** are provided.

The ultrasonic sensor **205** performs the operation shown in "Operation of Ultrasonic Sensor" described above. That is, a second diaphragm portion **207**B is vibrated in a direction perpendicular to the plane direction of a second supporting film **252** by the application of voltage to transmit ultrasonic waves at a frequency according to a predetermined drive voltage cycle. By receiving reflected waves from the object **10** (refer to FIG. **1**), the position of the object **10** is detected.

In the sensor array **281**, on the integrated supporting body **251**, **261**, the ultrasonic sensors **205** and the pressure sensors **206** which have a second frame body **254** and a frame body **264**, respectively, whose outer shape is a rectangle (square as an example in this case) are alternately arranged with a predetermined gap (width of the groove K) along a predetermined first direction (X-direction) and a second direction (Y-direction) perpendicular to the first direction (X-direction). The width of the groove K will be described in "Grasping Apparatus including Sensor Array" described later.

The ultrasonic sensor **205** is formed such that a top of the ultrasonic sensor **205** based on the common supporting body **251**, **261** is positioned low by the thickness of a sealing film **265** compared to a top of the pressure sensor **206**. In this case, the difference between the top positions is not essentially limited to the thickness of the sealing film **265**, and an ultrasonic sensor **205** having a top lower than the top of the pressure sensor **206** may be provided.

The ultrasonic sensor **205** and the pressure sensor **206** are separately arranged so that the common supporting body **251**, **261** is exposed in the gap between the ultrasonic sensor **205** and the pressure sensor **206**.

Instead of having the shape of exposing a portion of the common supporting body **251**, **261**, a structure in which the common supporting body **251**, **261** is hollowed may be used as a structure of the groove K. Especially when silicon is used for the common supporting body **251**, **261** and silicon oxide or ZrO_2 is used for a common supporting film **252**, **262**, high shape reproducibility can be provided.

Moreover, a step of forming the groove K to such a depth that the common supporting film **252**, **262** is exposed may be used. In this case, especially when a permanent resist is used for the frame body **264** and the second frame body **254**, high shape reproducibility can be provided because etching is stopped by the common supporting film **252**, **262**. Moreover, since etching can be performed using a developer at the same time as when the frame body **264** and the second frame body **254** are fabricated, the manufacturing steps can be shortened.

Moreover, it is allowed for the groove K to use a structure in which a frame body layer **270** made of a permanent resist used for forming the frame body **264** and the second frame body **254** is thinly left at the bottom of the groove on the supporting body side. In this case, a processing method for obtaining the configuration described above is described. However, this does not intend to limit a processing method but is introduced as an example for obtaining the structure. Irrespective of a processing method, it is sufficient to have the shape described above.

Method for Manufacturing Sensor Array

Next, a method for manufacturing a sensor array will be described. In this case, the ultrasonic sensor **205** and the pressure sensor **206** are formed on the same substrate (the common supporting body **251**, **261**). FIGS. **16**A to **17**D are step cross-sectional views for explaining manufacturing steps of the sensor array.

First, a single-crystal silicon substrate which serves as the common supporting body **251**, **261** (a thickness of about 650 μm) is prepared, and the surface of the substrate is thermally oxidized, whereby the first oxide film **252**A, **262**A formed of SiO_2 is formed so as to have a thickness of about 1 μm. By depositing Zr by sputtering and thermally oxidizing the same, a second oxide film **252**B, **262**B formed of ZrO_2 is formed on the first oxide film **252**A, **262**A so as to have a thickness of about 3 μm, whereby the common supporting film **252**, **262** is formed. FIG. **16**A shows the step cross-sectional view in a state where the steps so far are completed.

When the groove K is formed to a portion of the common supporting body **251**, **261** between the ultrasonic sensor **205** and the pressure sensor **206**, a step of forming the groove K is preferably performed in this state where the common supporting film **252**, **262** is formed, in view of the manufacturing steps. In the embodiment, the case of using, in a later step than this step, the step of forming the groove K to expose the common supporting body **251**, **261** will be described.

Next, in an argon gas atmosphere under a predetermined pressure, a conductor film constituting lower electrodes **932** and **832** is formed so as to cover the second oxide film **252**B, **262**B using sputtering deposition. A photoresist is coated on the surface side of the common supporting body **251**, **261** where the common supporting film **252**, **262** is formed, is exposed and developed by a photolithography method, and is further patterned by an etching process to form the lower electrodes **932** and **832**. This patterning is performed such that when a predetermined pressure equal to or less than an allowable pressure is applied to the pressure sensor **206**, the groove K where the pressure sensor **206** contacts the next pressure sensor **206** or the next ultrasonic sensor **205** is obtained in the gap between the pressure sensors **206** as finished articles or the gap between the ultrasonic sensor **205** and the pressure sensor **206** as finished articles.

FIG. **16**B shows the step cross-sectional view in a state where the steps so far are completed.

Next, a film for forming a piezoelectric film **931** and a second piezoelectric film **831** is deposited by sputtering so as to cover the lower electrodes **932** and **832**. By patterning by a photolithography method and an etching process, the piezoelectric film **931** and the second piezoelectric film **831** are formed. The piezoelectric film **931** and the second piezoelectric film **831** function as a pressure detecting portion and an ultrasonic transducer portion, respectively.

FIG. **16**C shows the step cross-sectional view in a state where the steps so far are completed.

Next, on the surface side of the common supporting body **251**, **261** where the lower electrodes **932** and **832** are arranged, a conductor film constituting upper electrodes **933** and **833** is deposited by sputtering. By patterning by a photolithography method and an etching process, the upper electrodes **933** and **833** are obtained, and a piezoelectric body **263** and a second piezoelectric body **253** each having an island-like shape are formed. Thus, a plurality of island-like ultrasonic transducer portions **275** (including the second supporting film **252** and the second piezoelectric body **253**) and a plurality of island-like pressure detecting portions **285** (including the supporting film **262** and the piezoelectric body **263**) are formed. The terms "island-like ultrasonic transducer portion" and "island-like pressure detecting portion" as used herein mean that the shape of a region where four layers of the supporting film, the lower electrode, the piezoelectric film, and the upper electrode are stacked is an independent island-like shape (piezoelectric body sensor portion forming step).

Next, the groove K which divides the common supporting film **252**, **262** is formed (groove forming step).

FIG. **16**D shows the step cross-sectional view in a state where the steps so far are completed.

Next, the common supporting body **251**, **261** is grinded by, for example, back grinding (BG) so that the thickness is reduced to about 200 μm. This is because when the common supporting body **251**, **261** which has been grinded to a desired thickness dimension is prepared in the steps so far, the common supporting body **251**, **261** may be warped during the manufacturing steps.

FIG. **16**E shows the step cross-sectional view in a state where the steps so far are completed.

Next, a permanent resist is coated as a frame body layer **270** on the upper electrodes **933** and **833** using a spin coating apparatus or a squeegee and dried. Thus, the frame body layer **270** is formed so as to cover the piezoelectric body **263** and the second piezoelectric body **253** (frame body layer forming step).

FIG. **16**F shows the step cross-sectional view in a state where the steps so far are completed.

If the groove K is formed in a step after forming the frame body layer **270**, the frame body layer **270** may be damaged. Therefore, the groove K is preferably formed in the steps so far. Specifically, the groove K includes a region which is formed using the same material as the frame body layer **270** and whose thickness is thin between the frame body **264** and the second frame body **254** next to each other. Alternatively, the groove K may include a region where the piezoelectric body **263** and the second piezoelectric body **253** are exposed between the frame body **264** and the second frame body **254** next to each other. Alternatively, the groove K may include a region where the common supporting body **251**, **261** is exposed between the frame body **264** and the second frame body **254** next to each other (the case of the embodiment). Alternatively, the groove K may be processed so as to include a region where the common supporting body **251**, **261** is exposed and further the common supporting body **251**, **261** is hollowed between the frame body **264** and the second frame body **254** next to each other. If the damage of the frame body layer **270** can be prevented even when the groove K is formed, the step of forming the groove K may be performed in a later step.

The frame body layer **270** formed on the upper electrodes **833** and **933** is exposed and developed by a photolithography method to pattern the frame body layer **270** such that the outer shape of the regions to serve as the frame body **264** and the second frame body **254** of the frame body layer **270** is a rectangle (square as an example in this case), and to pattern the frame body layer **270** so as to form a cavity **254**A and a cavity **264**A to expose the ultrasonic transducer portion **275** and the pressure detecting portion **285** inside the regions to serve as the frame body **264** and the second frame body **254**, whereby a plurality of frame bodies **264** and second frame bodies **254** are formed (frame body forming step). FIG. **16**G shows the step cross-sectional view in a state where the steps so far are completed.

Next, in the cavity **264**A of the frame body **264** which finally serves as the pressure sensor **206**, a silicone oil **220** is filled (filling step). In this case, the silicone oil **220** is not filled in the cavity **254**A of the second frame body **254** which finally serves as the ultrasonic sensor **205**. FIG. **17**A shows the step cross-sectional view in a state where the steps so far are completed.

Next, a dry film resist is coated as a sealing film **265**A on the upper surface of the frame body **264** and the second frame body **254** by a roll coating apparatus (film forming step). Thus, the cavity **264**A is sealed to serve as an inner space **266**. In this case, for coating without including air bubbles, coating is preferably performed in a reduced-pressure atmosphere. Moreover, for closely adhering the resist **265**A, coating is preferably performed while heating. It is not necessary to form the sealing film **265**A for the second frame body **254**. However, since it is technically difficult to selectively form a dry film resist as the sealing film **265**A using a roll coating apparatus, such a process that the sealing film. **265**A is once formed and then removed is performed as will be described later.

FIG. **17**B shows the step cross-sectional view in a state where the steps so far are completed.

Next, patterning is performed so as to leave the sealing film **265** located at a region overlapping with the frame body **264** and inside the frame body **264** to selectively remove the sealing film **265**A. FIG. **17**C shows the step cross-sectional view in a state where the steps so far are completed.

Next, the surface (back surface) of the common supporting body **251**, **261** on the side where the second supporting film **252** and the supporting film **262** are not present is dry etched such that, in plan view of the common supporting body **251**, **261**, openings are substantially overlapped with the openings inside the frame body **264** and the second frame body **254**. Then, a second opening **251**A and an opening **261**A having substantially the same dimensions as the inner diameter dimensions of the frame body **264** and the second frame body **254** are formed so as to overlap with the openings inside the frame body **264** and the second frame body **254**, whereby the ultrasonic sensor **205** and the pressure sensor **206** are formed. FIG. **17**D shows the step cross-sectional view in a state where the steps so far are completed.

By completing the steps so far, the sensor array **281** is formed.

After completing the manufacturing steps described above, a sensor substrate (not shown) may be bonded to the common supporting body **251**, **261** side, and the common supporting body **251**, **261** positioned in the gap between the pressure sensors **206**, the gap between the ultrasonic sensors **205**, and the gap between the pressure sensor **206** and the ultrasonic sensor **205** may be cut by means such as etching. In this case, the transmission of vibrations is suppressed between the pressure sensor **206** and the ultrasonic sensor **205** by the sensor substrate. Therefore, the sensor array **281** which can precisely measure pressure is obtained.

Grasping Apparatus Including Sensor Array

Next, the operation of the grasping apparatus **1** including the sensor array **281** will be described using FIGS. **22** to **24**. FIG. **22** is a block diagram for explaining a grasping operation of the grasping apparatus **1**; FIG. **23** is a flowchart for explaining the grasping operation of the grasping apparatus **1**; and FIGS. **24**A to **24**C are timing diagrams for explaining the grasping operation of the grasping apparatus **1**.

FIG. **22** is a block diagram where a control device and a drive mechanism block of the grasping apparatus **1**, which are not shown in FIG. **1**, are additionally illustrated. Similarly to the illustration in FIG. **1**, the grasping apparatus **1** includes the supporting member **2** and the pair of arms **3** as grasping arms which extend from the supporting member **2**. The arms **3** grasp the object **10**. On the grasping surface **31** with which the arm **3** contacts the object **10**, any of the sensor array **4** (refer to FIG. **2**), the sensor array **281** (refer to FIG. **13**), and a sensor array **481** (refer to FIG. **20**) may be attached. In the embodiment, the case where the sensor array **281** is attached will be described.

As shown in FIG. **22**, the grasping apparatus **1** includes a control device **104** for drivingly controlling the arms **3**, and a drive mechanism **105**.

The control device **104** includes a signal detecting unit **101**, a grasp detecting unit **102**, and a drive control unit **103**.

The signal detecting unit **101** detects a distance signal from, for example, the ultrasonic sensor **205** (refer to FIGS. **14**A and **14**B) when the object **10** is away from the sensor array **281**.

The grasp detecting unit **102** detects a pressure signal from the object **10** and the pressure sensor **206** (refer to FIGS. **14**A and **14**B) of the sensor array **281** provided on the grasping surface **31**.

In the embodiment, the signal detected from the signal detecting unit **101** and the signal detected from the grasp detecting unit **102** are transmitted to the drive control unit **103**. When the object **10** is away from the sensor array **281**, the signal detected from the signal detecting unit **101** (the ultrasonic sensor **205**) is transmitted to the drive mechanism **105** described later. When the object **10** is in contact with the sensor array **281**, the pressure signal detected from the grasp detecting unit **102** (for example, the pressure sensor **206**) is transmitted from the drive control unit **103** to the drive mechanism **105**. Although, in this case, an example in which the distance signal and the pressure signal are output as digital signals is shown, also analog signal output can be similarly processed. For example, control may be performed using an OP amplifier or the like, or signals may be processed by AD conversion.

The drive mechanism **105** includes a power source **116** and a power transmitting portion **117**.

The power source **116** is, for example, a motor. To the motor, a signal (control signal) for controlling the rotational speed is transmitted from the drive control unit **103**. When it is sufficient that the object **10** and the sensor array **281** satisfy a poor positional accuracy (they are sufficiently away from each other), a signal to keep the rotational speed of the motor constant is transmitted from the drive control unit **103**.

When the object **10** and the sensor array **281** require a precise positional accuracy, that is, when they are approaching each other, a signal to reduce the rotational speed of the motor is transmitted from the drive control unit **103**. A set distance (PC) **109** for changing the rotational speed of the motor is previously written as a data table in a memory **118** included in the control device **104**. That is, the set distance (PC) **109** is a threshold value for changing the driving speed and is appropriately set according to the size of the grasping apparatus **1** or the form of the object **10**.

When the pressure signal just corresponds with the value (set pressure (SP) **110**) at which the grasping of the object **10** can be performed, the motor is stopped and the position of the arms **3** is kept. Also the set pressure for stopping the motor is previously written in the memory **118** included in the control device **104**.

The power transmitting portion **117** converts mechanical output transmitted from the power source **116** to the grasping movement of the arms **3** with a not-shown gear or the like.

Subsequently, graphs (timing diagrams) of FIGS. **24**A to **24**C will be described.

In the graphs shown in FIGS. **24**A to **24**C, the horizontal axes (X-axes) are taken as time axes showing the same time series for the graphs A, B, and C. Hereinafter, each of the graphs will be described.

FIG. **24**A is a graph showing a relation between the moving speed (speed of grasping operation) of the arm **3** and time. The vertical axis (Y-axis) of the graph shown in FIG. **24**A shows the moving speed (speed of grasping operation: SA) and direction of the arm **3**, in which the positive value (positive direction of Y-axis) shows that the arm **3** moves in a direction approaching the object **10**.

The speed of grasping operation is divided into three levels in the embodiment: a constant speed (CS) when remote (R) **111**; a low speed (LS) in proximity detection (PP) **112**; and the speed of a microoperation (SS) in a grasping operation (MS) **113**.

FIG. **24**B is a graph showing a relation between the distance between the ultrasonic sensor **205** and the object **10**, and time. The vertical axis (Y-axis) of the graph shown in FIG. **24**B is a distance signal (DS) showing the distance between the ultrasonic sensor **205** and the object **10**. When the ultrasonic sensor **205** contacts the object **10**, 0 is output in principle.

FIG. **24**C is a graph showing a relation between the pressure signal of the pressure sensor **206** and time. The vertical axis (Y-axis) of the graph shown in FIG. **24**C is a pressure signal (PS) showing the pressure between the pressure sensor **206** and the object **10**. When the pressure sensor **206** is away from the object **10**, 0 is output in principle.

FIG. **23** is a flowchart showing a flow of a grasping method. Next, the grasping operation by the grasping apparatus **1** will be described according to the flowchart shown in FIG. **23**. An operation in each step is executed based on the control signal from the control device **104** described above.

In Step S**1**, when the grasping surfaces **31** of the arms **3** as grasping arms shown in FIG. **22** are remote from the object **10** (the distance between the grasping surface **31** and the object **10** is greater than the set distance (PC) **109** described above), an operation to bring the arms **3** close to the object **10** is performed at uniform speed (constant speed (CS)) as shown in FIG. **24**A.

This operation is applied when the distance signal shown in FIG. **24**B is equal to or greater than the set distance (PC) **109** described above, which shows a state before TO in the timing diagrams in FIGS. **24**A to **24**C.

In Step S**2**, it is determined based on a distance signal detected by the ultrasonic sensor **205** whether the distance between the grasping surface **31** and the object **10** is less than the set distance (PC) **109**. If the distance signal between the arm. **3** and the sensor array **281** is less than the set distance (PC) **109** described above, the process proceeds to Step S3. If the distance signal is the set distance or greater, the process returns to Step S**1**. This operation corresponds to T**0**-T**1** in the timing diagrams in FIGS. **24**A to **24**C.

In Step S**3**, the driving speed of the arm **3** is reduced to the low speed (LS). By reducing the speed, the distance between the arm **3** and the object **10** can be adjusted more precisely. This operation corresponds to T**1**-T**3** in the timing diagrams in FIGS. **24**A to **24**C.

In Step S**4**, the contact between the grasping surface **31** and the object **10** is determined based on the pressure signal detected by the grasp detecting unit **102**.

If the grasping surface **31** is not in contact with the object **10**, the driving speed reduced in Step S3 is maintained.

If contact detection (CD) between the grasping surface **31** and the object **10** is made, the process proceeds to Step S5. This operation corresponds to T**3**-T**4** in the timing diagrams in FIGS. **24**A to **24**C.

In Step S5, based on the pressure signal detected by the grasp detecting unit **102**, the arms **3** shown in FIG. **22** are caused to perform the microoperation (SS) to finely adjust pressure given to the object **10**. This operation corresponds to T**4**-T**5** in the timing diagrams in FIGS. **24**A to **24**C.

In Step S**6**, determination is made based on a high and low relation between pressure received by the pressure sensor **206** and the set pressure (SP) **110** set with a range from a lower limit pressure to an upper limit pressure. If the pressure received by the pressure sensor **206** is lower than the lower limit pressure of the set pressure (SP) **110**, the process returns to Step S**5**. If the pressure of the pressure sensor **206** is higher than the upper limit pressure of the set pressure **110**, Step S**8** is executed. If the pressure received by the pressure sensor **206** falls between the lower limit pressure and the upper limit pressure, the process proceeds to Step S**7**. This operation corresponds to T**5**-T**9** in the timing diagrams in FIGS. **24**A to **24**C.

In Step S**7**, press control is stopped, and a holding operation is performed. This operation corresponds to T**9** or later in the timing diagrams in FIGS. **24**A to **24**C.

By performing the above operations, the grasping apparatus **1** can grasp the object **10** at high speed with a highly accurate pressure.

During the holding operation, since the pressure sensor **206** differs from the ultrasonic sensor **205** in height by the thickness of the sealing film. **265**, the ultrasonic sensor **205** does not contact the object **10** even when the pressure sensor **206** is slightly compressed by pressure. Therefore, in a usual grasping state, the ultrasonic sensor **205** can escape deterioration due to pressure, thereby maintaining high reliability.

In this case, when the deformation of the frame body **264** of the pressure sensor **206** is increased (strongly grasping state) with an abnormally increased pressure due to some factors, the groove K is filled, and the frame body **264** of the pressure sensor **206** contacts the second frame body **254** of the ultrasonic sensor **205**, as shown in FIGS. **14**B and **15**A. By the contact of the frame body **264** with the second frame body **254**, the characteristics of the ultrasonic sensor **205** change.

That is, the width of the groove K is preferably set such that when pressure having a smaller value than the allowable pressure, near the allowable pressure of the pressure sensor **206**, is applied, the frame body **264** contacts the second frame body **254** of the ultrasonic sensor **205**. By providing such a width, the reliability of the pressure sensor **206** can be improved.

Moreover, when too much pressure equal to or greater than the allowable pressure is applied to the pressure sensor **206** in a short time, a control signal from the ultrasonic sensor **205** is delayed, and the pressure sensor **206** may be excessively collapsed and deteriorated. When excessive pressure is applied to the pressure sensor **206** and the pressure sensor **206** is deformed in the thickness direction by the thickness of the sealing film **265** (difference between the tops) or more, the ultrasonic sensor **205** starts deforming such that the central portion expands more than both ends with respect to the height direction of the second frame body **254**. Therefore, as shown in FIG. **15**B, the pressure sensor **206** and the ultrasonic sensor **205** next to each other function as each other's reinforcing materials, which can prevent the deterioration of the pressure sensor **206** or the ultrasonic sensor **205** caused by excessive collapse.

According to the configuration of the pressure sensor, the method for manufacturing the sensor array, and the grasping apparatus including the sensor array of the embodiment described above, the following advantageous effects can be provided.

Since the pressure sensor **206** differs from the ultrasonic sensor **205** in height by the thickness of the sealing film **265**, the ultrasonic sensor **5** does not contact the object **10** even when the pressure sensor **206** is slightly compressed. Therefore, in a usual grasping state, the ultrasonic sensor **205** can escape deterioration due to pressure, thereby maintaining high reliability.

When the deformation of the frame body **264** of the pressure sensor **206** is increased, the groove K is filled, and the frame body **264** of the pressure sensor **206** contacts the second frame body **254** of the ultrasonic sensor **205**. By the contact of the frame body **264** with the second frame body **254**, the characteristics of the ultrasonic sensor **205** change. In this case, by setting the groove K such that when the pressure sensor **206** is deformed within the elastic limit thereof, the frame body **264** contacts the second frame body **254** of the ultrasonic sensor **205**, the reliability of the pressure sensor **206** can be improved.

When excessive pressure is applied to the pressure sensor **206** and the pressure sensor **206** deforms in the thickness direction by the thickness of the sealing film **265** or more, the ultrasonic sensor **205** starts deforming such that the central portion expands more than both ends with respect to the height direction of the second frame body **254**. Therefore, the pressure sensor **206** and the ultrasonic sensor **205** next to each other function as each other's reinforcing materials, which can prevent the deterioration of the pressure sensor **206** or the ultrasonic sensor **205** caused by excessive collapse.

Patterning is performed so as to leave the sealing film **265** located at the region overlapping with the frame body **264** and inside the frame body **264** to selectively remove the sealing film **265**A, whereby the height of the second frame body **254** can be different from that of the frame body **264**, making it possible to form the pressure sensor **206** and the ultrasonic sensor **205** including a step portion without increasing the number of manufacturing steps.

By performing the grasping operation according to the flowchart shown in FIG. **22**, the grasping apparatus **1** can grasp the object **10** at high speed with highly accurate pressure.

Hereinafter, further another embodiment (fourth embodiment) according to the invention will be described based on the drawings.

Fourth Embodiment

Configuration of Sensor Array

FIG. **25** is a cross-sectional view showing a sensor array **4**C according to the fourth embodiment. The sensor array **4**C includes a sensor substrate **45**C which supports an ultrasonic sensor **5**C and a pressure sensor **6**C.

The ultrasonic sensor **5**C and the pressure sensor **6**C include through-electrodes **41**C in a second supporting body **51**C and a supporting body **61**C, respectively, and a wiring **43**C provided on the sensor substrate **45**C is connected to the through-electrodes **41**C, whereby the ultrasonic sensor and the pressure sensor are electrically conducted to a not-shown control portion via the wiring. A gap is provided between second frame bodies **54**C, between frame bodies **64**C, and between the second frame body **54**C and the frame body **64**C. A groove LB as a gap is provided between the second supporting body **51**C and the supporting body **61**C. With the groove LB, edge cutting is performed between the ultrasonic sensors next to each other, between the pressure sensors next to each other, and between the ultrasonic sensor and the pressure sensor next to each other, whereby they are divided (independent). As will be described below, the sensor array **4**C is similar to that of the first embodiment described above except for including the sensor substrate **45**C and including the groove LB between the second supporting body **51**C and the supporting body **61**C. Moreover, a common supporting body may be used for the second supporting body **51**C and the supporting body **61**C.

The term "edge cutting" as used herein means a state where the ultrasonic sensors next to each other or the pressure sensors next to each other are independent. A state where the supporting body is not completely separated but a separating groove is partially formed is also referred to as "edge cutting".

Since the pressure sensor and the ultrasonic sensor are each supported by the sensor substrate and mechanically divided while including the supporting body, they do not interfere with each other, making it possible to detect pressure with high accuracy.

In the sensor array **4**C, the sensors **5**C and **6**C may be alternately provided at equal distances along, for example, a predetermined first direction (X-direction) and a second direction (Y-direction) perpendicular to the first direction (X-direction).

Also in this case, a structure in which a protective film **55**C is removed may be used. Then, since the height from the sensor substrate **45**C to a top of the pressure sensor **6**C is higher than the height from the sensor substrate **45**C to a top of the ultrasonic sensor **5**C, the top of the ultrasonic sensor **5**C does not contact an object. Therefore, the ultrasonic sensor **5**C can escape deterioration due to pressure and maintain high reliability (resistance to pressure).

Configuration of Ultrasonic Sensor

FIG. **25** is the cross-sectional view showing the configuration of the sensor array **4**C including the ultrasonic sensor **5**C.

The ultrasonic sensor **5** includes a second supporting film, a second piezoelectric body **53**C, the second frame body **54**C, and the protective film **55**C which are stacked in order on the second supporting body **51**C.

The second supporting film and the second piezoelectric body **53**C constitute an ultrasonic transducer portion.

The second supporting body **51**C is formed of a single-crystal silicon substrate and formed to a thickness of about 200 μm. In the second supporting body **51**C, a circular second opening **51**D, in plan view when the second supporting film is viewed from the film thickness direction, is formed by dry etching.

The second supporting film closes the second opening **51**D of the second supporting body **51**C and is configured of a first oxide film **52**C and a second oxide film **52**D which are stacked on the surface of the second supporting body **51**C. The first oxide film **52**C is formed of, for example, SiO_2 and formed to a thickness of about 1 μm by thermally oxidizing the surface of the single-crystal silicon substrate of the second supporting body **51**C. The second oxide film **52**D is formed of, for example, ZrO_2 and formed on the first oxide film **52**C so as to have a thickness of about 3 μm by depositing Zr by sputtering and thermally oxidizing the same.

The diameter dimension of the second opening **51**D is appropriately set in a range from, for example, about one hundred μm to several hundreds μm according to the natural frequency of a second diaphragm portion. The second diaphragm portion vibrates, whereby ultrasonic waves are transmitted toward the object **10** (refer to FIG. **1**) side.

The second piezoelectric body **53**C is a film-like member which is formed concentrically with the second opening **51**D in plan view of the sensor. The diameter dimension of the second piezoelectric body **53**C is smaller than the diameter dimension D' of the second opening **51**D. The second piezoelectric body **53**C includes a second piezoelectric film **531**C and electrodes (a lower electrode **532**C and an upper electrode **533**C) which apply voltage to the second piezoelectric film **531**C. The term "diameter dimension of piezoelectric body" as used herein means the diameter of a region where the lower electrode, the piezoelectric film, and the upper electrode are stacked.

The second piezoelectric film **531**C is formed of, for example, lead zirconate titanate (PZT) made into a film. The lower electrode **532**C is formed below the second piezoelectric film **531**C. The upper electrode **533**C is formed on the second piezoelectric film **531**C.

The upper electrode **533**C and the lower electrode **532**C are drawn through a not-shown drawing portion which is formed on the back side (the second opening **51**D side) of the ultrasonic sensor **5**C, are connected to a not-shown control portion of the sensor array **4**C, and apply a predetermined voltage to the piezoelectric film **531**C based on a voltage signal input from the control portion.

The second frame body **54**C is cylindrically formed of a permanent resist made of a synthetic resin material having flexibility and formed to a thickness of about 100 μm to 600 μm. Moreover, with a cylindrical inner peripheral wall provided in the second frame body **54**C, a cavity along the film thickness direction of the second supporting film is formed. The second frame body **54**C is formed such that in plan view when viewed from the film thickness direction of the second supporting film, a cylindrical inner peripheral edge of the cavity which is cylindrical is positioned to be overlapped with an inner peripheral edge of the second opening **51**D or positioned outside of the inner peripheral edge. In this case, the inner diameter dimension of the second frame body **54**C is formed so as to have substantially the same dimension as that of the second opening **51**D (the case of overlapping). In the cavity of the second frame body **54**C, a membrane is contained. For example, the second frame body **54**C can be formed using permanent resist TMMR™ S2000 of TOKYO OHKA KOGYO CO., LTD.

The protective film **55**C is a portion which contacts the object **10**, is formed of a dry film resist made of a synthetic resin material having flexibility, similarly to the second frame body **54**C, and is formed to a thickness of about 100 μm. Moreover, the protective film **55** is formed in a ring shape to cover an upper end surface of the second frame body **54**C. For example, the protective film **55** can be formed using dry film resist TMMF™ S2000 of TOKYO OHKA KOGYO CO., LTD.

Configuration of Pressure Sensor

FIG. **25** is the cross-sectional view showing the configuration of the sensor array **4**C including the pressure sensor **6**C.

The pressure sensor **6**C detects pressure when, for example, the grasping surfaces **31** of the arms **3** of the grasping apparatus **1** (refer to FIG. **1**) grasp the object **10**. The pressure sensor **6**C includes a supporting film, a piezoelectric body **63**C (a piezoelectric film **631**C, a lower electrode **632**C, and an upper electrode **633**C), the frame body **64**C, and a sealing film **65**C which are stacked in order on the supporting body **61**C.

The supporting film closes an opening **61**D of the supporting body **61**C and is configured of a first oxide film **62**C and a second oxide film **62**D which are stacked on the surface of the supporting body **61**C. The supporting film and the piezoelectric body **63**C constitute a pressure detecting portion **9**C.

The frame body **64**C is formed cylindrically, similarly to the second frame body **54**C of the ultrasonic sensor **5**C, and has a cavity. In the cavity, a membrane including a diaphragm portion which is a portion of the supporting film where the opening **61**A is closed and the piezoelectric body **63**C which is provided on the diaphragm portion is contained.

Thus, a silicone oil **20**C as a pressure medium is filled in the inner space **66**C formed of a cylindrical inner peripheral wall of the cavity, the sealing film **65**C, and the pressure detecting portion.

The sealing film **65**C closes the inner space **66**C to seal the silicone oil **20**C. As the material to be filled in the inner space **66**C, any material which disperses pressure may be used. Other than the silicone oil **20**C, for example, a silicone rubber, a polymer gel, a synthetic gel, a natural gel, a polymer resin, or the like may be used. The frame body **64**C is formed such that in plan view when viewed from the film thickness direction of the supporting film, a cylindrical inner peripheral edge of the cavity which is cylindrical is positioned to be overlapped with an inner peripheral edge of the opening **61**D or positioned outside of the inner peripheral edge. In this case, the inner diameter dimension of the frame body **64**C is formed so as to have substantially the same dimension as the diameter dimension D of the opening **61**D (in the case of overlapping).

The sealing film **65**C is a portion which contacts the object **10** (refer to FIG. **1**), similarly to the protective film **55**C, and is formed in a circular shape so as to close the inner space **66**C to seal the silicone oil **20**C. Moreover, the sealing film **65**C is a portion which seals the silicone oil **20**C and contacts the object **10**. The sealing film **65**C is formed of the same material as that of the protective film **55**C. For example, the sealing film **65**C can be formed using dry film resist TMMF™ S2000 of TOKYO OHKA KOGYO CO., LTD.

Since the silicone oil **20**C is filled in the inner space **66**C, an impact when the object **10** contacts the sealing film **65**C is dispersed over the entire membrane **8**.

When a pressure medium filled in the inner space **66**C is a material which does not leak, such as a polymer gel, the sealing film **65**C may not be provided.

Method for Manufacturing Sensor Array

Next, a method for manufacturing a sensor array using a step of forming the groove LB, in which the sensor substrate **45**C is bonded to the lower surface side of the common supporting body **51**C, **61**C and thereafter, edge cutting is performed for the common supporting body **51**C, **61**C while leaving at least a portion of the sensor substrate **45**C, will be described. FIGS. **26** to **27**C are step cross-sectional views showing manufacturing steps of the sensor array. In FIGS. **26** to **27**C, manufacturing steps of the ultrasonic sensor **5**C are shown on the left while manufacturing steps of the pressure sensor **6**C are shown on the right.

In the following description, a pair of ultrasonic sensor **5**C and pressure sensor **6**C are described. However, this is applicable also to the case where a plurality of ultrasonic sensors **5**C and pressure sensors **6**C are provided (refer to FIG. **2**).

As for the way of dividing, the pressure sensors **6**C or the ultrasonic sensors **5**C may be once divided into individual ones, and thereafter, they may be bonded to the sensor substrate **45**C on another occasion. Moreover, some of the pressure sensors **6**C or the ultrasonic sensors **5**C may be collectively divided.

The description for steps of preparing a single-crystal silicon substrate which serves as the common supporting body **51**C, **61**C; forming, on one surface thereof, the common supporting film (formed of the first oxide film **52**C, **62**C and the second oxide film **52**D, **62**D), the piezoelectric body **63**C, the second piezoelectric body **53**C, the frame body **64**C, and the second frame body **54**C; filling a silicone oil in the cavity of the frame body **64**C serving as the pressure sensor **6**C; and coating a dry film resist corresponding to the protective film **55**C and the sealing film **65**C using a roll coating apparatus is similar to that of the method for manufacturing the sensor array of the first embodiment described above. Therefore, the description is omitted. FIG. **26** shows the cross-sectional view in a state where the step of coating the protective film **55**C and the sealing film **65**C is completed. The supporting film and the piezoelectric body **63**C constitute the pressure detecting portion **9**C.

An example of forming the groove LB, in which the sensor substrate **45**C after this step is bonded to the lower surface side of the common supporting body **51**C, **61**C and thereafter, edge cutting is performed for the second supporting body **51**C and the supporting body **61**C while leaving at least a portion of the sensor substrate **45**C, will be described below.

First, through-holes **40**C are formed through the common supporting body **51**C, **61**C using dry etching, and thereafter, an insulating layer is formed on the side wall of the through-hole **40**C by CVD or the like. Next, Au is embedded in the through-hole **40**C by plating, whereby the through-electrode **41**C is formed. Next, the coated dry film resist corresponding to the protective film **55**C and the sealing film **65**C is exposed and developed by a photolithography method. Further by an etching process, the protective film **55**C and the sealing film **65**C are patterned into a desired shape. Thereafter, the lower surface side of the common supporting body **51**C, **61**C is dry etched to form the second opening **51**D and the opening **61**D having substantially the same diameters as the inner diameter dimensions of the second frame body **54**C and the frame body **64**C. FIG. **27**A shows the cross-sectional view in a state where the steps so far are completed.

Next, edge cutting is performed to divide the ultrasonic sensor **5**C and the pressure sensor **6**C. FIG. **27**B shows the cross-sectional view in a state where the steps so far are completed.

Next, the ultrasonic sensors **5**C and the pressure sensors **6**C are arranged and fixed on the sensor substrate **45**C with a gap having the width of the groove LB, whereby the sensor array **4**C including the plurality of ultrasonic sensors **5**C and pressure sensors **6**C on the sensor substrate **45**C is formed. FIG. **27**C shows the cross-sectional view in a state where the steps so far are completed.

Although, in the embodiment, an example of including the ultrasonic sensors **5**C and the pressure sensors **6**C has been described, a sensor array only including the pressure sensors **6**C can be formed similarly.

In the sensor array of the embodiment, the following advantageous effects can be provided in addition to the advantageous effects in the first to third embodiments.

Since the ultrasonic sensor **5**C and the pressure sensor **6**C are arranged via the groove therebetween (independently), it is possible to suppress the transmission of vibrations of the membrane of the ultrasonic sensor to the pressure sensor. That is, since the influence of vibrations from the ultrasonic sensor on the piezoelectric body or diaphragm portion of the membrane of the pressure sensor is reduced, the pressure sensor can detect pressure with good accuracy.

Since the ultrasonic sensor **5**C and the pressure sensor **6**C are once divided and then bonded to the sensor substrate **45**C, the embodiment can also deal with the sensor substrate **45**C larger than the second supporting body **51**C or the supporting body **61**C. Moreover, since the second supporting body **51**C or the supporting body **61**C is usually more expensive than the sensor substrate **45**C, the manufacturing cost can be reduced by once dividing the ultrasonic sensor and the pressure sensor and then bonding them to the sensor substrate **45**C.

Modifications of Embodiments

The invention is not limited to the embodiments described above, but various kinds of changes or improvements can be added to the embodiments described above. Modified examples will be described below.

FIRST MODIFIED EXAMPLE

A description will be made with reference to FIG. **8**. FIG. **8** shows a modified example according to the invention.

In the embodiment, the inner diameter dimension of the frame body **64** has substantially the same dimension as the diameter dimension D of the opening **61**A. However, the modified example differs from the embodiment in that the inner diameter dimension of the frame body **64** is larger than the diameter dimension D of the opening **61**A.

SECOND MODIFIED EXAMPLE

A description will be made with reference to FIG. **2**. In FIG. **2**, the pressure sensors **6** and the ultrasonic sensors **5** are arranged at equal distances from each other on the common supporting body **51**, **61** in the embodiment. However, they are not limited to this arrangement, but any arrangement may be adopted. Specifically, as long as the pressure sensors **6** and the ultrasonic sensors **5** are uniformly arranged dispersedly in the plane of the common supporting body **51**, **61**, a variation does not occur between a position at which the ultrasonic sensor **5** recognizes an object and a position at which the pressure sensor **6** detects a force grasping the object.

THIRD MODIFIED EXAMPLE

A description will be made with reference to FIGS. **3**A and **3**B. In FIG. **3**A, the ultrasonic sensor **5** is configured to transmit ultrasonic waves toward the membrane **8** side. However, the ultrasonic sensor **5** may be configured to transmit ultrasonic waves also toward the second opening **51**A side.

FOURTH MODIFIED EXAMPLE

A description will be made with reference to FIG. **7**B. In FIG. **7**B, the frame body **64** and the second frame body **54** of the ultrasonic sensor **5** and the pressure sensor **6** are formed independently of each other. However, the second frame body **54** and the frame body **64** next to each other may be integrated, so that the pressure sensor **6** and the ultrasonic sensor **5** may be configured so as to be paired.

FIFTH MODIFIED EXAMPLE

A description will be made with reference to FIGS. **9** and **10**A. As shown in FIGS. **9** and **10**A, an example in which the pressure sensors **106** each of which has the frame body **164** whose outer shape is a square are arranged via the groove G on the supporting body **161** included in the sensor array **180** has been described. However, the outer shape is not limited to a rectangle. For example, a shape, such as an isosceles triangle, a right triangle, a trapezoid, or a regular hexagon, which fills a plane may be arranged at distances corresponding to the groove G. In the case of using the outer shape described above, when excessive pressure is applied to the pressure sensor **106**, the pressure sensor is pushed to the next frame body **164** at a plane. Therefore, compared to the case where, for example, the outer shape of the frame body **164** is a circle or the like, resistance to high pressure can be further improved.

Moreover, as shown in FIG. **13**, when the example is applied to the sensor array **281** having also the ultrasonic sensors **205**, some of the pressure sensors **206** may be replaced with the ultrasonic sensors **205**. Also in this case, a similar advantageous effect can be obtained.

SIXTH MODIFIED EXAMPLE

A description will be made with reference to FIGS. **10**A and **14**A. As shown in FIGS. **10**A and **14**A, as the description for the sensor arrays **180** and **281**, the sensor arrays in which the planar shape of diaphragm portions **107** and **207** and the second diaphragm portion **207**B is a circle have been described. However, the planar shape may be an ellipse, a rectangle, a regular hexagon, or any other shape. By making the outer shape ellipsoidal or rectangular for example, it is possible to improve the effective areas of the diaphragm portions **107** and **207** and the second diaphragm portion **207**B in the frame body **64** and the second frame body **54**. Moreover, by making the outer shape regular hexagonal, and accordingly, by making the outer shape of the frame body **64** and the second frame body **54** regular hexagonal, the effective areas of the diaphragm portions **107** and **207** and the second diaphragm portion **207**B can be highly secured.

SEVENTH MODIFIED EXAMPLE

A description will be made with reference to FIG. **14**A. In the case of the sensor array **281** including the ultrasonic sensors **205** in addition to the pressure sensors **206** shown in FIG. **14**A, the outer shape of the frame body **264** (**254**) may be a circle or any other shape without limiting to the shape which fills a plane. As long as the pressure sensor **206** and the ultrasonic sensor **205** are arranged to be spaced from each other by the groove K, when the pressure sensor **206** is deformed within the elastic limit thereof, the frame body contacts the second frame body **254** of the ultrasonic sensor **205**, and a signal from the ultrasonic sensor **205** is modulated by this contact. Therefore, this modulated amount is detected, and pressure is adjusted, whereby the reliability of the pressure sensor **206** can be improved.

EIGHTH MODIFIED EXAMPLE

A description will be made with reference to FIGS. **10**A to **10**C, **13**, **14**A, **14**B, and **18** to **21**B.

FIG. **18** is a perspective view of a sensor array. FIG. **19**A is a plan view of the sensor array; FIG. **19**B is a cross-sectional view taken along line A-A' of the plan view shown in FIG. **19**A; and FIG. **19**C is a schematic cross-sectional view when the sensor array is subjected to pressure from the object **10**. FIG. **20** is a perspective view of a sensor array. FIG. **21**A is a plan view of the sensor array shown in FIG. **20**; and FIG. **21**B is a cross-sectional view taken along line A-A' of the plan view shown in FIG. **21**A.

A sensor array **300** shown in FIG. **18** includes a plurality of pressure sensors **306** mounted on a supporting body **361**. In the sensor array **180** shown in FIGS. **10**A to **10**C, the sealing film **165** is provided only for the pressure sensor **106**, but, as shown in FIG. **18**, this may have a configuration including a sealing film **365** over the entire surface of the sensor array so that the sealing film is common to frame bodies **364**. In this case, pressure applied to the pressure sensor **306** is dispersed by the sealing film **365** as shown in FIGS. **19**B and **19**C because the sensor array has a structure shown in FIGS. **18** and **19**A. Therefore, the sensor array **300** which is less susceptible to breakage can be provided.

In the case of the sensor array **481** including ultrasonic sensors **405** in addition to pressure sensors **406**, the sensor array may have a configuration including, instead of the sealing film **265** shown in FIGS. **13**, **14**A, and **14**B, a sealing film **465** excepting a region of the ultrasonic sensors **405** as shown in FIG. **20**. The sensor array **481** shown in FIG. **20** includes the plurality of ultrasonic sensors **405** in addition to the plurality of pressure sensors **406** mounted on a common supporting body **451**, **461**. As shown in FIGS. **21**A and **21**B, the sealing film **465** is provided on a frame body **464** but the sealing film **465** is not provided on a second frame body **454**. In this case, pressure applied to the pressure sensor **406** is dispersed by the sealing film **465** because the sensor array has the structure shown in FIGS. **20**, **21**A, and **21**B. Therefore, the sensor array **481** which is less susceptible to breakage can be provided.

NINTH MODIFIED EXAMPLE

A description will be made with reference to FIG. **2**.

In the first embodiment, an example in which the pressure sensors **6** and the ultrasonic sensors **5** are integrated on one substrate has been described. This may be separated by, for example, dicing and then bonded to another substrate for use. In this case, especially when the pressure sensors **6** or the ultrasonic sensors **5** are formed in a wide range, the cost can be reduced because a large substrate is not required.

TENTH MODIFIED EXAMPLE

A description will be made with reference to FIGS. **14**A, **14**B, and **28**.

In the third embodiment as shown in FIG. **14**B, electrical conduction is established between the ultrasonic sensor **205** and the pressure sensor **206**, and the not-shown control portion which controls the ultrasonic sensor **205** and the pressure sensor **206** via the electrode pattern (wiring) formed on the second supporting film **252** and the supporting film **262** (in a direction from the common supporting body **251**, **261** toward the frame body **264** and the second frame body **254**). That is, the wiring is formed on the upper side of the sensor array **281**, and the ultrasonic sensor **205** and the pressure sensor **206** are electrically conducted to the control portion via the wiring. In this case, since the wiring located at the region overlapping with the groove K for edge cutting is removed, the wiring is formed so as to avoid the portion of the groove K. In the modified example, on the other hand, wirings **44**A and **44**B for electrically conducting to the through-electrodes **41**C are formed by sputtering Au and then patterning the same as shown in FIG. **28**. The wirings **44**A and **44**B are provided. Therefore, in plan view of the common supporting body **251**, **261**, the wirings **44**A and **44**B can be formed also in the portion of the groove K for edge cutting. That is, the wiring region can be formed also in the region of the groove K for edge cutting, which can improve the degree of freedom of the wiring pattern.

What is claimed is:

1. A sensor array comprising:

a pressure sensor which has

a supporting body which has an opening,

a pressure detecting portion which includes

a supporting film provided on the supporting body and having a diaphragm portion closing the opening, and

a piezoelectric body provided on the diaphragm portion and deflecting to output an electric signal,

a frame body which has, on the pressure detecting portion, a cylindrical cavity along a film thickness direction of the supporting film, and is formed, in plan view when viewed from the film thickness direction of the supporting film, at a position where a cylindrical inner peripheral wall of the cavity overlaps with an inner peripheral edge of the opening, or outside of the inner peripheral edge of the opening,

a sealing film which closes the frame body, and

a pressure medium which is filled in an inner space formed of the cylindrical inner peripheral wall of the cavity, the sealing film, and the pressure detecting portion; and

an ultrasonic sensor which has

a second supporting body having a second opening, and

an ultrasonic transducer portion including a second supporting film which is provided on the second supporting body and has a second diaphragm portion closing the second opening, and a second piezoelectric body which is provided on the second diaphragm portion and deflects by the application of voltage.

2. The sensor array according to claim **1**, wherein

the ultrasonic sensor further includes a second frame body which has, on the ultrasonic transducer portion, a cylindrical second cavity along a film thickness direction of the second supporting film, and is formed, in plan view when viewed from the film thickness direction of the second supporting film, at a position where a cylindrical inner peripheral wall of the second cavity overlaps with an inner peripheral edge of the second opening, or outside of the inner peripheral edge of the second opening.

3. The sensor array according to claim **2**, wherein

the sensor array includes a plurality of the pressure sensors and a plurality of the ultrasonic sensors, and

a gap is formed between frame bodies of the pressure sensors next to each other, between second frame bodies of the ultrasonic sensors next to each other, or between a frame body of the pressure sensor and a second frame body of the ultrasonic sensor next to each other.

4. The sensor array according to claim **3**, wherein

the supporting body and the second supporting body are a common supporting body which is common to them, and

a height from the common supporting body to a top of the pressure sensor is higher than a height from the common supporting body to a top of the ultrasonic sensor.

5. The sensor array according to claim **3**, wherein

the pressure sensors and the ultrasonic sensors have a two-dimensional array structure in which the pressure sensor and the ultrasonic sensor are alternately arranged.

6. The sensor array according to claim **3**, wherein

a dimension of the gap is set such that when a first pressure is applied to the pressure sensor, the frame body deforms to contact the frame body of the next pressure sensor or contact the second frame body of the next ultrasonic sensor, and

the first pressure is smaller than an allowable pressure of the pressure sensor.

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